SEA LEVEL RISE ADAPTATION STRATEGY REPORT

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Prepared for:

CITY OF MORRO BAY
INCORPORATED JULY 17, 1964

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1. Introduction

Sea level rise (SLR) has the potential to increase the frequency and severity of coastal hazards affecting coastal assets and resources in the City of Morro Bay (City). The City is susceptible to coastal hazards such as inundation, flooding, and bluff/dune erosion associated with extreme waves and water levels. Exposure of a coastal asset or resource to a hazard may result in varying impacts, depending on its function and its resiliency, which is its ability to withstand and recover from these events. For assets with low resiliency, intervention in the form of adaptation will be needed.

A thoughtful and effective approach to adaptation, beginning with the planning process, can reduce adverse impacts from SLR and result in a more resilient coastal community. Conversely, ad-hoc emergency actions can lack consideration of long-term community goals and vision, as well as secondary impacts associated with the repair. Some emergency repairs may be met with opposition from regulatory agencies. Similarly, physical repair or alteration of hard shoreline protection structures may be challenging from a regulatory perspective in the future. Agencies are increasingly rejecting protection approaches for non-critical structures in favor of soft solutions or managed retreat options.

As part of the City *Community Baseline Assessment* (CBA) supporting the City's General Plan and Local Coastal Program (General Plan/LCP) Update, Moffatt & Nichol (M&N) prepared a SLR vulnerability assessment that investigated how current and future coastal hazards may impact these resources. The vulnerability assessment found that the most vulnerable coastal resources in the City during the year 2100 timeframe were beaches, state parks, coastal parcels, and transportation infrastructure.

Adaptation strategies were developed for three sites in the City (Figure 1-1). Locations were selected to represent the general exposure of a type of hazard or asset. These sites were selected based on coordination with the City and the California Coastal Commission (CCC). The selected sites are described below:

- ***Highway 1*** – The Highway 1 study area includes a 1,700-linear foot (lf) stretch of Caltrans-owned highway in the northern portion of the City (Figure 1-2). Highway 1 adaptation strategies are intended to be applicable to other vulnerable coastal transportation routes.
- ***Morro Rock Parking Lot*** **-** The Morro Rock parking lot consists of an approximately 5-acre, decomposed granite surface lot with informal vehicle parking (Figure 1-3). The lot supports access to the most popular beach in the City. Adaptation strategies for Morro Rock parking lot represent alternatives for similar vulnerable coastal parking lots and recreational resources in the City.
- ***Embarcadero Waterfront*** – The Embarcadero Waterfront study area covers an 1,800-lf portion of the Morro Bay shoreline, fronting the former Dynegy power plant (Figure 1-4). This reach of shoreline is representative of much of the developed Embarcadero in the City, which supports various commercial uses.

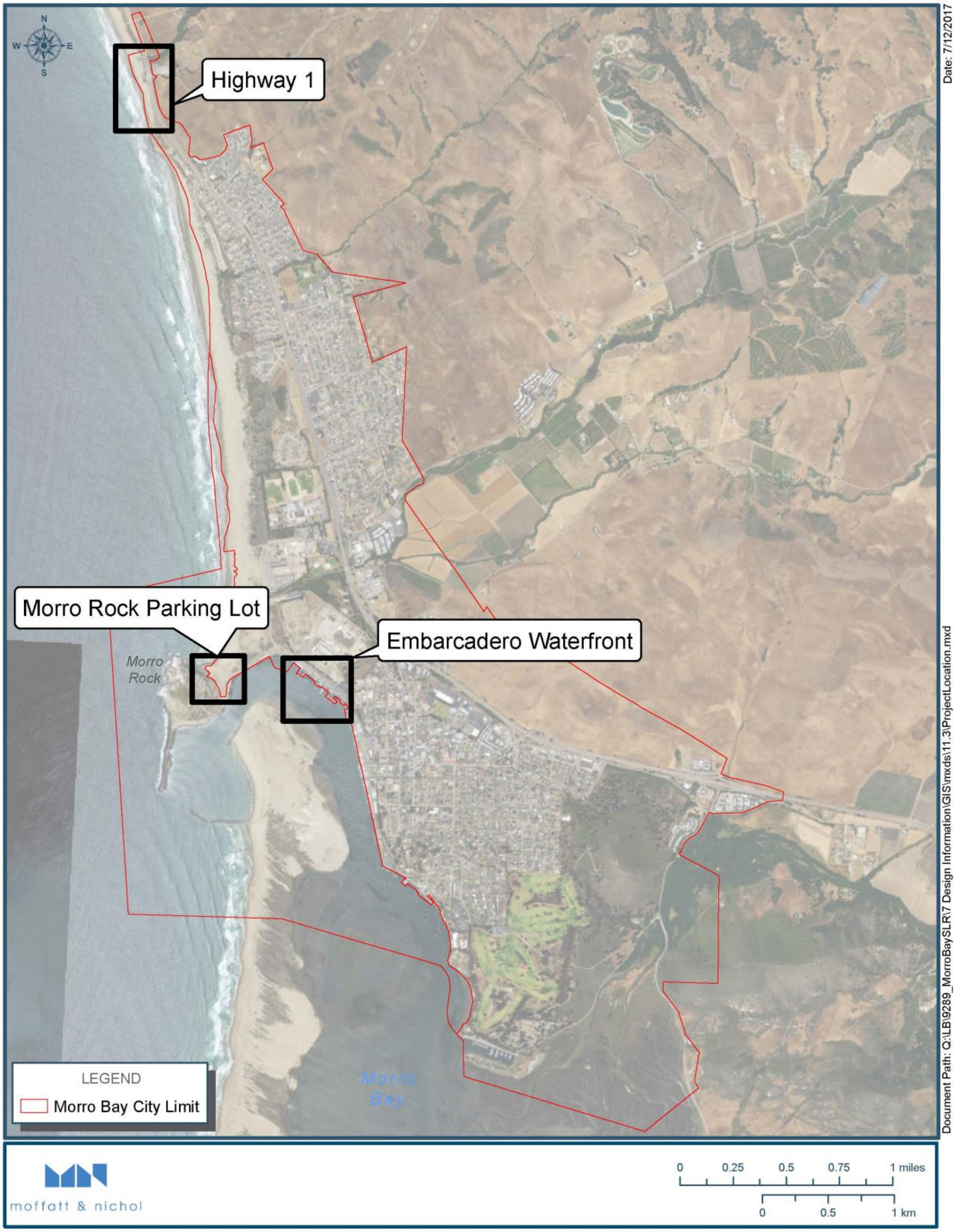


FIGURE 1-1. STUDY AREAS

FIGURE 1-2. HIGHWAY 1 STUDY AREA

FIGURE 1-3. MORRO ROCK PARKING LOT STUDY AREA

FIGURE 1-4. EMBARCADERO WATERFRONT STUDY AREA

2. SCOPE OF WORK

This report presents the analysis of three feasible coastal adaptation strategies for three sites within the City to inform policy development and long-term planning decisions throughout the City's coastal zone. Sites selected for the analysis are Highway 1, Morro Rock parking lot, and the Embarcadero Waterfront. Adaptation strategies for each site are separated by the general classifications of protection, accommodation, and retreat, as defined by the CCC's Sea Level Rise Guidance (2015). The study addresses physical changes related to storm water, coastal erosion, and SLR. The analysis includes the description of each potential alternative with an analysis of pros and cons, and potential adverse impacts of each alternative to public access and coastal resources (e.g., traffic impacts, loss of beach area for recreation, etc.). Appropriate triggers for action are identified for each of these strategies. Triggers can include certain sea level measurements, beach widths, and/or repeated damage/flooding of a coastal asset.

3. Study Approach

The following sections define SLR projections, adaptation strategies, trade-offs and secondary impacts of adaptation, and adaptation cost assessments.

3.1. Sea Level Rise Projections

The nearest, long-term sea level record in proximity to the study area is the Port San Luis tide gage (Station 9412110) operated by the National Oceanic and Atmospheric Administration (NOAA). The gage is located on the Harford Pier, which has been collecting data since 1948. These data are applicable to the open-ocean coastline in central California and are summarized in Table 3-1. Elevations in this study are relative to the NAVD88 vertical datum.

Table 3-1. Water Levels in Port San Luis (1983-2001 Tidal Epoch)

Description	Datum	Elevation (ft, NAVD88)
Highest Observed Water Level (1/18/1973)	Maximum	7.57
Highest Astronomical Tide	HAT	7.02
Mean Higher-High Water	MHHW	5.26
Mean High Water	MHW	4.54
Mean Sea Level	MSL	2.72
Mean Low Water	MLW	0.96
North American Vertical Datum of 1988	NAVD88	0.00
Mean Lower-Low Water	MLLW	-0.08
Lowest Astronomical Tide	LAT	-2.07
Lowest Observed Water Level (01/07/1951)	Minimum	-2.48

(Source: NOAA 2016)

SLR projections used in the Community Baseline Assessment (CBA) used projections from "Sea-Level Rise for the Coasts of California, Oregon, and Washington" (NRC 2012). The study used the high range for each of the horizon years as a conservative measure. These SLR projections are shown in Table 3-2.

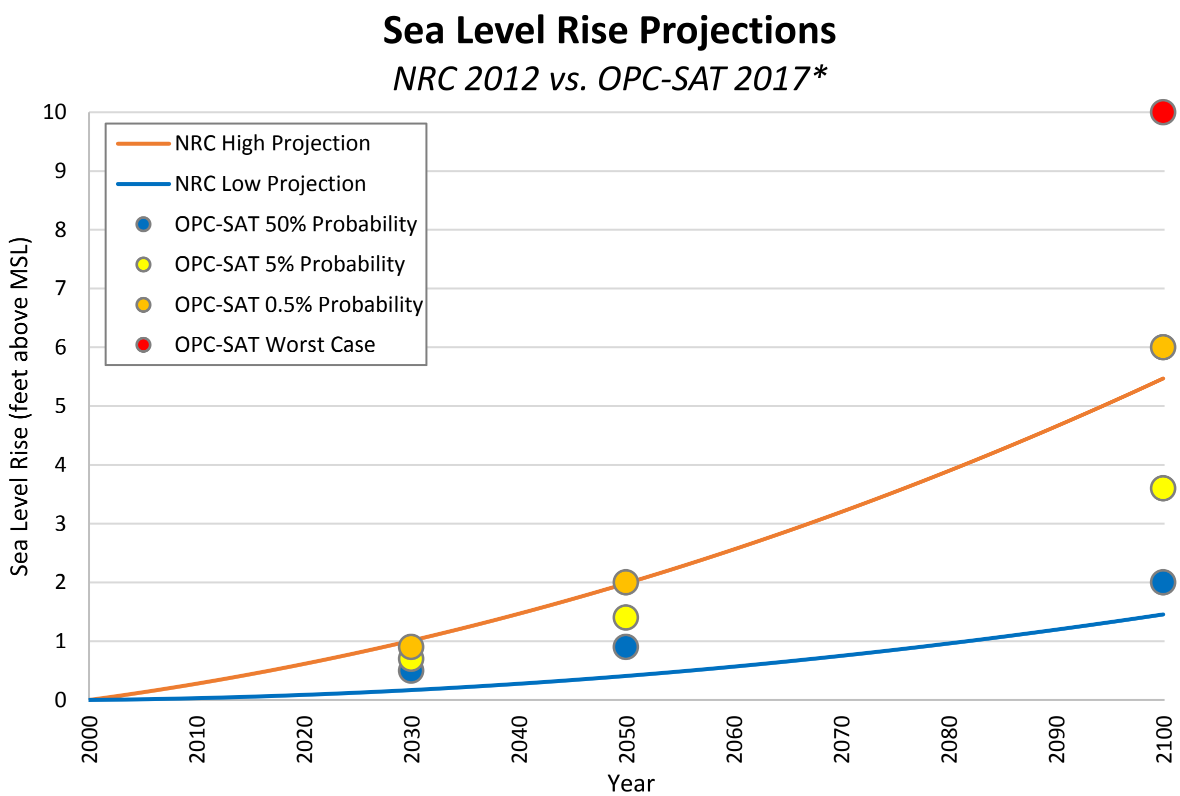
Table 3-2. Sea Level Rise Projections

Year	Projected Sea Level Rise (ft)	Projection Uncertainty (ft, +/-)	Low Range (ft)	High Range (ft)
2030	0.5	0.2	0.2	1.0
2050	0.9	0.3	0.4	2.0
2100	3.1	0.8	1.5	5.5

(Source: National Research Council 2012).

A new scientific study titled "Rising Seas in California – An Update on Sea-Level Rise Science" (OPC-SAT 2017) for the State of California suggests the potential for higher SLR projections than NRC 2012 by the year 2100 and beyond timescales. These new SLR projections were given probabilities of occurrence by years 2030, 2050, and 2100. The OPC-SAT (2017) and NRC (2012) SLR projections are compared in

Figure 3-1. It is important to note that OPC-SAT (2017) probablities do not include the more recent extreme ice loss scenario from the DeConto and Pollard (2016) study. The OPC-SAT (2017) report adds the H++ scenario to address this recent study's findings. However, since OPC-SAT (2017) probabilities do not consider the ice loss science of DeConto and Pollard (2016), probabilities are potentially underestimated, though the degree by which the probabilities may be underestimated is currently unknown.



**OPC-SAT (2017) projections assume emission scenario RCP 4.5. Worst Case scenario (Red Circle) developed by DeConto & Pollard (2016).*

FIGURE 3-1. SEA LEVEL RISE PROJECTIONS – A COMPARISON OF BEST AVAILABLE SCIENCE

3.2. COASTAL FLOODING AND EROSION MODELLING

Current and future coastal flooding and erosion modelling was performed and mapped in support of the General Plan/LCP Update. The primary coastal hazards that occur in Morro Bay are flooding (as a result of extreme coastal wave runup and river discharge events), inundation (as a result of daily tides), and bluff and dune erosion. These hazard zones are described below:

- Flood Hazard Zone – Flood events are typically short in duration (i.e., hours) and occur episodically in association with extreme waves and precipitation events (e.g., 100-year return period events). The flood hazard zone shows the limits of extreme water levels associated with a 100-year return event and NRC (2012) High SLR Projections for years 2050 and 2100. The Bruun Rule was used to evolve the shoreline to a future equilibrium position prior to conducting the wave modelling. Thus, the flood hazard zone considers SLR-driven shoreline evolution.

- Inundation Hazard Zone – Areas within the inundation hazard zone will be subject to daily wetting and drying associated with tides. A mean high water tide elevation and NRC (2012) High SLR Projections for years 2050 and 2100 were used as a proxy to represent future inundation hazard zones.
- Bluff Hazard Zone – Rising sea levels may result in the increased erosion of coastal bluffs due to more frequent exposure to wave attack. The bluff hazard zone is the area between the existing and future bluff edge resulting from a composite 100-year wave event and NRC (2012) High SLR Projections for years 2050 and 2100.
- Dune Hazard Zone – Coastal dunes will respond to SLR by migrating landward. The dune hazard zone represents the area between the current and future dune toe resulting from a composite 100-year wave event and NRC (2012) High SLR Projections for years 2050 and 2100.

3.3. Adaptation Strategies Considered

SLR adaptation can be generally categorized into protection, accommodation, and retreat. It is important to note that maintaining the status quo or doing nothing can also result in expenditures and impacts to coastal resources. Thus, the adaptation strategies were compared against maintaining the status quo option. The three adaptation strategies are described below as defined by the CCC (2015).

- Protection – Protection strategies refer to those strategies that employ some sort of engineered structure or other measure to defend development (or other resources) in its current location without changes to the development itself. Protection strategies can be further divided into "hard" and "soft" defensive measures or armoring.
    - "Hard" armoring refers to engineered structures such as seawalls, revetments, and bulkheads that defend against coastal hazards like wave impacts, erosion, and flooding.
    - "Soft" armoring refers to the use of natural or "green" infrastructure like beaches, dune systems, wetlands, and other systems to buffer coastal areas.
- Accommodation - Accommodation strategies refer to those strategies that employ methods that modify existing developments or design new developments to decrease hazard risks and thus increase the resiliency of development to the impacts of SLR. Flood-proofing and relocation of vulnerable utilities to higher elevation are examples of accommodation.
- Retreat – Retreat strategies are those strategies that relocate or remove existing development out of hazard areas and limit the construction of new development in vulnerable areas. These strategies include land use designations and zoning ordinances that encourage building in more resilient areas or gradually removing and relocating existing development. Acquisition and buy-out programs, transfer of development rights programs, and removal of structures where the right to protection was waived (i.e., via permit condition) are examples of strategies designed to encourage managed retreat.

3.4. Adaptation Trade-offs and Secondary Impacts

It is important to recognize primary impacts of adaptation strategies, which often come with trade-offs in terms of "who" benefits from each. For example, with traditional shoreline protection strategies, the private property owner takes the greatest benefit through protection of their existing structures; however, it is an accepted consequence that hard shoreline protection can result in loss of beach area and possible impacts on coastal access and littoral processes. Almost all adaptation strategies also have associated secondary impacts. Another example is the potential impacts to visual resources associated with accommodation strategies that elevate buildings or shoreline protection structures through increased height limits to protect against elevated levels of flooding. These factors are discussed in this report.

3.5. Adaptation Costs

Costs for the various adaptation strategies were developed with initial construction costs as well as an approximate 20-year lifecycle/maintenance cost. The costs associated with various adaptation strategies are provided in Table 3-3 below. Cost estimates provided are opinions of probable construction costs based on reasonable professional judgement and experience, recognizing that costs for labor, equipment, or materials, and contractors' methods of determining prices or bidding vary from project to project and location to location. No engineering and design, or environmental compliance work is included in the adaptation cost estimates. Engineering design and environmental work can range from 10 to 20% of the total construction costs. Costs to acquire land or perform environmental mitigation were also not included in these cost estimates.

Table 3-3. Rough Order of Magnitude Costs for Adapation Strategies

Adaptation Strategy	Approx. Initial Construction Cost ($/unit)	Approx. 20-yr Maintenance Costs ($/unit)	Assumptions
Re-align Revetment	$90/ton	$600/lf	Assumes the physical moving of a revetment. Does not include purchasing any additional rock.
Construct Revetment	$2,500/lf	$600/lf	Revetment of 3- to 5-ton stone with a crest elevation of +18 feet (ft) MLLW.
Raise Revetment	$200/ton	$600/lf	Raise revetment crest 3 to 5 ft with 2- to 3-ton stone.
Beach Nourishment	$10/cubic yard (cy)	$48/cy	Assumes a nourishment project is constructed that "piggy-backs" on the existing U.S. Army Corps of Engineers (USACE) harbor dredging program. City pays for dredging and placement. $2/cy is to be added for each mile of separation between sand source and placement. If "piggy-back" construction is not an option, initial construction costs increase to ~$40/cy.
Dune Construction	$10/cy	$20/cy	Assumes construction of a sand dune, without inclusion of rock or vegetation. Sand for the dune would "piggy-back" on the existing USACE harbor dredging program. City pays for dredging and placement. $2/cy is to be added for each mile of separation between sand source and placement. Maintenance of ½ the total dune volume assumed necessary every 5 years.
Construct Bridge	$150-300/square foot (sf)	$50,000	Assumes construction of a deep foundation, multi-span bridge with a 75-year design life. Maintenance costs for one-time joint seal replacement.
Construct New Highway	$1,900/lf	No change from existing conditions	Assumes construction of 72 ft wide, 2,800 ft long highway while maintaining existing traffic configuration. Does not include cost to purchase necessary land from County of San Luis Obispo.

Adaptation Strategy	Approx. Initial Construction Cost ($/unit)	Approx. 20-yr Maintenance Costs ($/unit)	Assumptions
Construct Raised Parking	$10/sf	Assumed no maintenance required	Assumes re-grading and raising parking lot to accommodate SLR. Construct new asphalt surface. Does not include upgrades to facilities.
Gangway	$20,000/Gangway	$0	Furnish and install new gangway. Assumes 6 ft wide by 34 ft long brow with aluminum deck slat and railing.
Guide Piles	$70/vertical linear foot (vlf)	$0	Furnish and install new 16-inch (in.) diameter prestressed concrete guide pile. Typical pile vertical length is 44 ft.
Install Storm Drain Check Valves	$3,000/unit	$0	Cost estimate for storm drain check valve.

Regarding beach nourishment and dune construction adaptation strategies, the USACE annually dredges sediment from the Morro Bay entrance channel and places it in the nearshore and surfzone along Morro Strand State Beach. The average annual dredging rate from 2006 to 2014 was 185,000 cubic yards per year (cy/yr) (USACE 2016). This project may present an opportunity to beneficially reuse this sediment to construct beaches and sand dunes. Estimated costs for dune or beach nourishment assumes piggy-backing on this program. Costs were based on other federal and local sponsor cost-share projects. Collaboration with USACE would be needed to explore use of these materials and unit costs.

4. STUDY SITES

Study sites include Highway 1, Morro Rock parking lot, and Embarcadero Waterfront, each of which was assessed for its respective vulnerabilities to SLR. In this section, the coastal setting at these sites is described and existing and future coastal vulnerabilities are summarized.

4.1. HIGHWAY 1

Along the open coast in the northern reach of the City, a low-lying segment of Highway 1 is fronted by a rock revetment, just south of Toro Creek Bridge. The highway's lowest point is at an elevation of approximately +22 ft, NAVD88. The highway is heavily traveled and provides a vital north-south transportation linkage to communities along the central coast. Highway 1 is owned and operated by Caltrans. Highway 1 northbound (NB) and southbound (SB) are two lane roads providing an annual average daily travel (ADT) of 24,900 vehicles for the year 2015 (Caltrans 2015). An existing revetment located just south of the Chevron seawall extends approximately 550 lf and reaches a maximum crest height of approximately 22 ft, NAVD88. The revetment structure serves to protect the highway from undermining.

Based on the results of hazard modeling in the CBA, Highway 1 is currently vulnerable to flooding and erosion. Flooding can create traffic delays or make roads impassable, which would constrict vital transportation and evacuation routes. Existing shoreline protection is not continuous throughout the reach and appears undersized to accommodate increased water levels. Thus, Highway 1 is currently not resilient to SLR. Existing conditions within the study area are shown in Photo 1 through Photo 4.

PHOTO 1. CHEVRON BULKHEAD WALL AND BEACH ACCESS POINT

PHOTO 2. HIGHWAY 1 REVETMENT

PHOTO 3. HIGHWAY 1 REVETMENT AND DUNE SYSTEM

PHOTO 4. HIGHWAY 1 BRIDGE OVER TORO CREEK

Highway 1 was found to be potentially vulnerable to inundation, flooding, and bluff erosion hazards as a result of SLR (Figure 4-1). The vulnerability assessment assumed that existing shore protection was either not in place or was easily overwhelmed. A summary of findings from the vulnerability assessment, as described in the CBA, are as follows:

- Inundation Hazards – Under the 2050 SLR scenario, the study area is protected from inundation hazards. Under the 2100 SLR scenario, the study area is exposed to tidal inundation (i.e., daily wetting and drying).
- Flood Hazards **-** Under the 2050 SLR scenario, the entire study area is exposed to flooding during extreme storms. Under the 2100 SLR scenario, Highway 1 will be vulnerable to flooding during less extreme, higher frequency storms.
- Bluff Erosion Hazards **-** By year 2050, a 70 ft wide bluff hazard zone encompasses the southern end of Highway 1 SB. By year 2100, a 130 ft wide bluff hazard zone encompasses Highway 1 NB and SB.

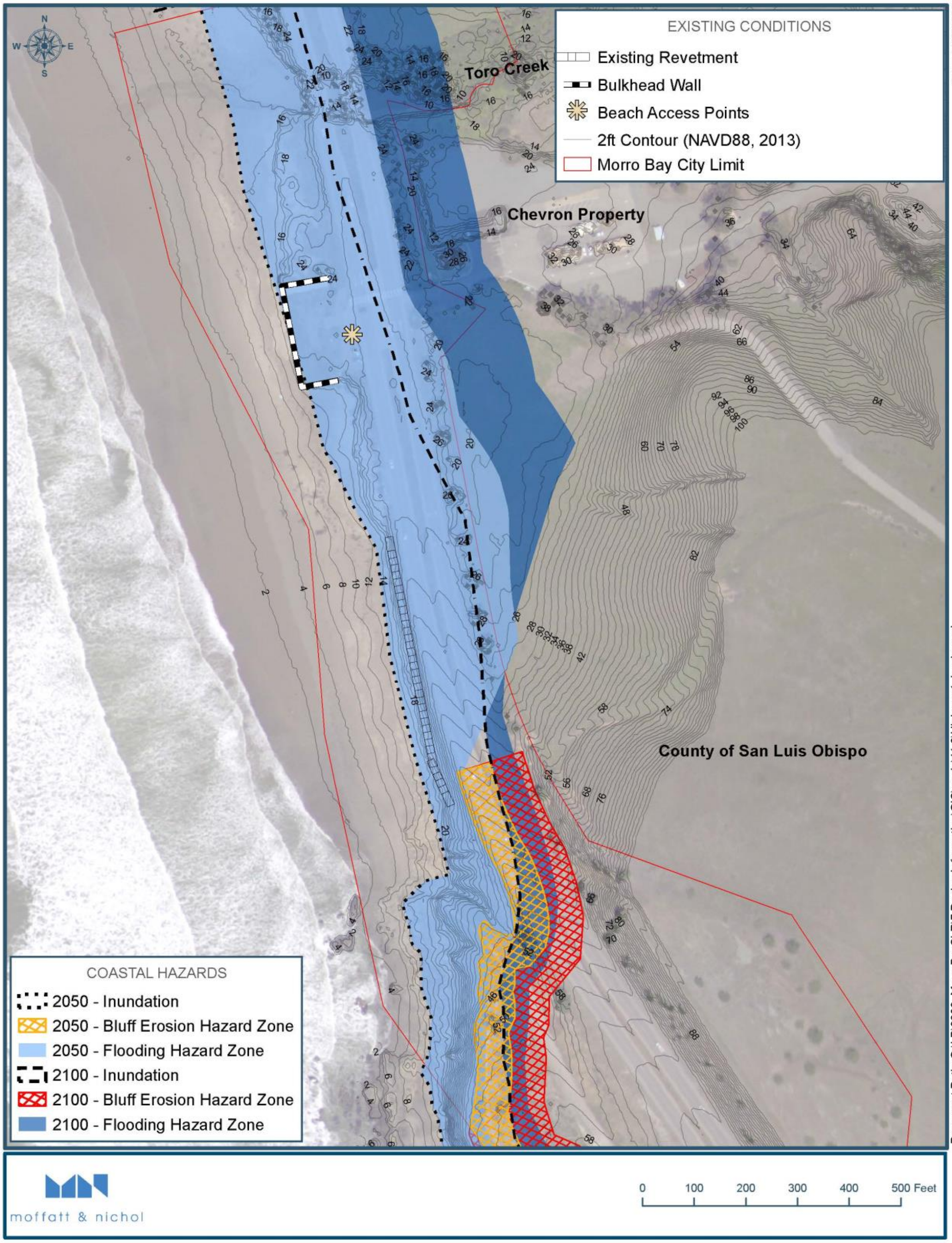


FIGURE 4-1. COASTAL HAZARDS IN THE HIGHWAY 1 STUDY AREA (HIGH SLR PROJECTION+100-YR STORM)

4.2. MORRO ROCK PARKING LOT

The Morro Rock parking lot is built on reclaimed land that acts to separate the ocean north of Morro Rock from the bay. The USACE constructed the land in the 1930s as part of navigational improvements in the bay. The land is protected on both ocean and bay sides by rock revetment slopes. The rock revetment crest elevations and the parking lot grade are approximately +15 ft NAVD88.

Based on the results of hazard modeling in the CBA, the Morro Rock parking lot is currently vulnerable to flooding. Flooding results in public access constraints, maintenance, and cleanup costs. The frequency and severity of flooding will increase as sea levels rise. Further, the seaward facing revetment will suffer increasing wave impacts with increasing water levels, potentially scouring the revetment toe and de-stabilizing the structure. Failure of the revetment could result in erosion of this land that serves to protect navigation within Morro Bay. The CBA assumes that the revetment is sufficient in design to protect this landmass. Further analysis may be warranted to verify this. Existing conditions within the study area are shown in Photo 5 through Photo 7.

PHOTO 5. REVETMENT AT MORRO ROCK PARKING LOT

PHOTO 6. DUNES NORTH OF MORRO ROCK PARKING LOT

PHOTO 7. PUBLIC AMENITIES AT THE MORRO ROCK PARKING LOT

Morro Rock parking lot was found to be potentially vulnerable to flooding hazards as a result of SLR (Figure 4-2). The vulnerability assessment assumed that existing shore protection (i.e., revetment) was sufficient to prevent erosion/inundation of the reclaimed land. Further study of the revetment to confirm its condition is recommended. A summary of findings from the vulnerability assessment, as described in the CBA, are as follows:

- Inundation Hazards - Under the 2050 and 2100 SLR scenarios, the study area is protected from inundation hazards.

- Flooding Hazards - Under the 2050 high SLR scenario, coastal access and recreation opportunities will remain viable in this area; however, temporary disruptions during high surf events are more likely and widespread. Under the 2100 high SLR scenario, Morro Rock parking lot is almost completely encompassed by the flood hazard zone.

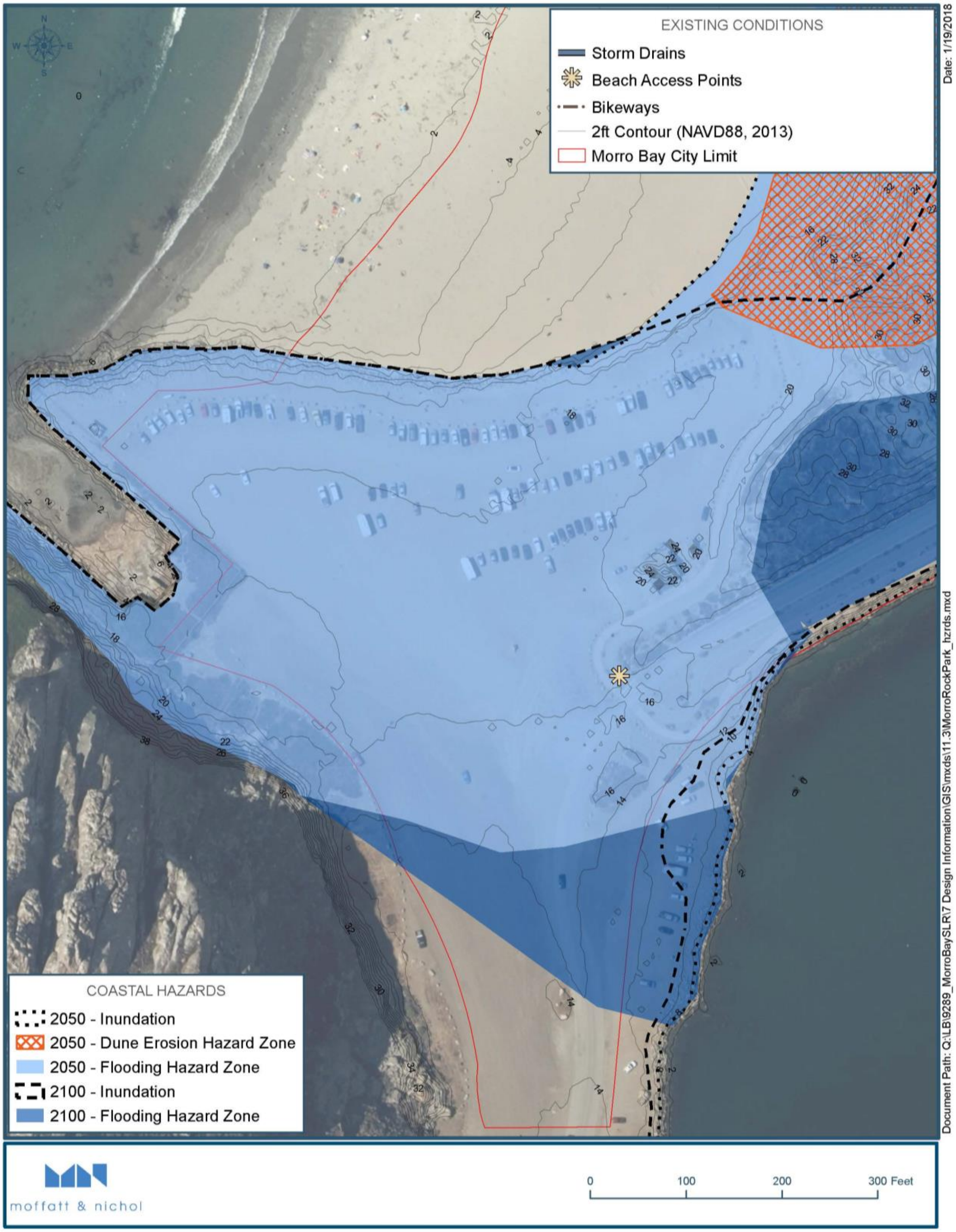


FIGURE 4-2. COASTAL HAZARDS IN THE MORRO ROCK PARKING LOT STUDY AREA (HIGH SLR+100-YR STORM)

4.3. EMBARCADERO WATERFRONT

In the 1940s, land was reclaimed along the existing Embarcadero Waterfront with material dredged from the harbor and placed behind a rock seawall. The Embarcadero Waterfront within the study area sits at an approximate elevation of +14 ft NAVD88 (Photo 8). The fixed piers and wharves in the area also stand at approximately +14 ft NAVD88. Underdeck utilities are at an elevation of approximately +11 ft NAVD88 (Photo 9). Gangways connect the roadway and piers to floating docks within the study area (Photo 10 through Photo 12). Floating docks are contained by guide piles that typically reach elevations of +11 ft NAVD88. Storm drains that discharge to the harbor have invert elevations of approximately +9 ft NAVD88 (Photo 13). For context, the existing MHHW elevation in the City is +5.26 ft NAVD88. Note that elevations of assets along the Embarcadero Waterfront vary and site-specific analysis of other locations along this reach is recommended.

The Embarcadero shoreline consists of rock revetments, rip rap, and bulkhead walls of various design (i.e., concrete, steel sheetpile, and timber) that serve to protect the land from erosion while allowing access to waterfront amenities. SLR vulnerabilities to this area include increased water levels destabilizing shoreline protection devices, impacts to existing waterfront asset systems (i.e., docks, piers, wharfs) and eventual tides overtopping the structures and inundating the land. The CBA assumed that all waterfront structures are sufficient in design to protect the shoreline. Further analysis may be warranted to verify this.

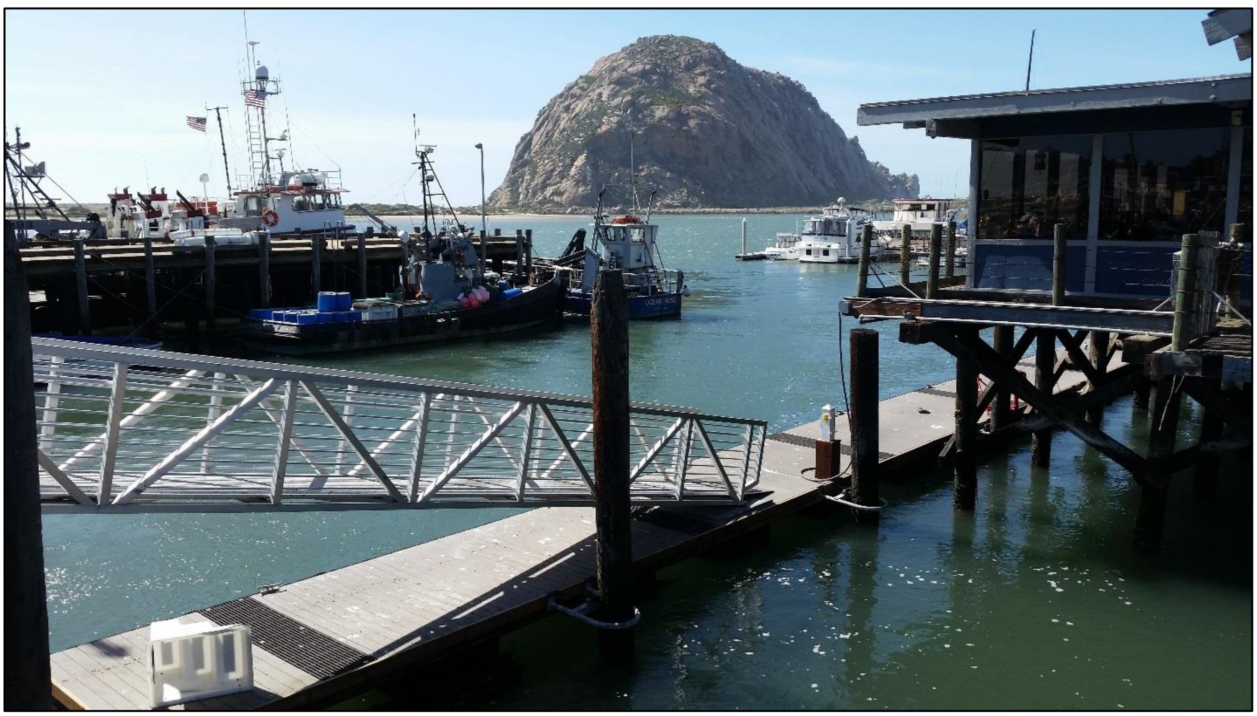


PHOTO 8. EMBARCADERO WATERFRONT

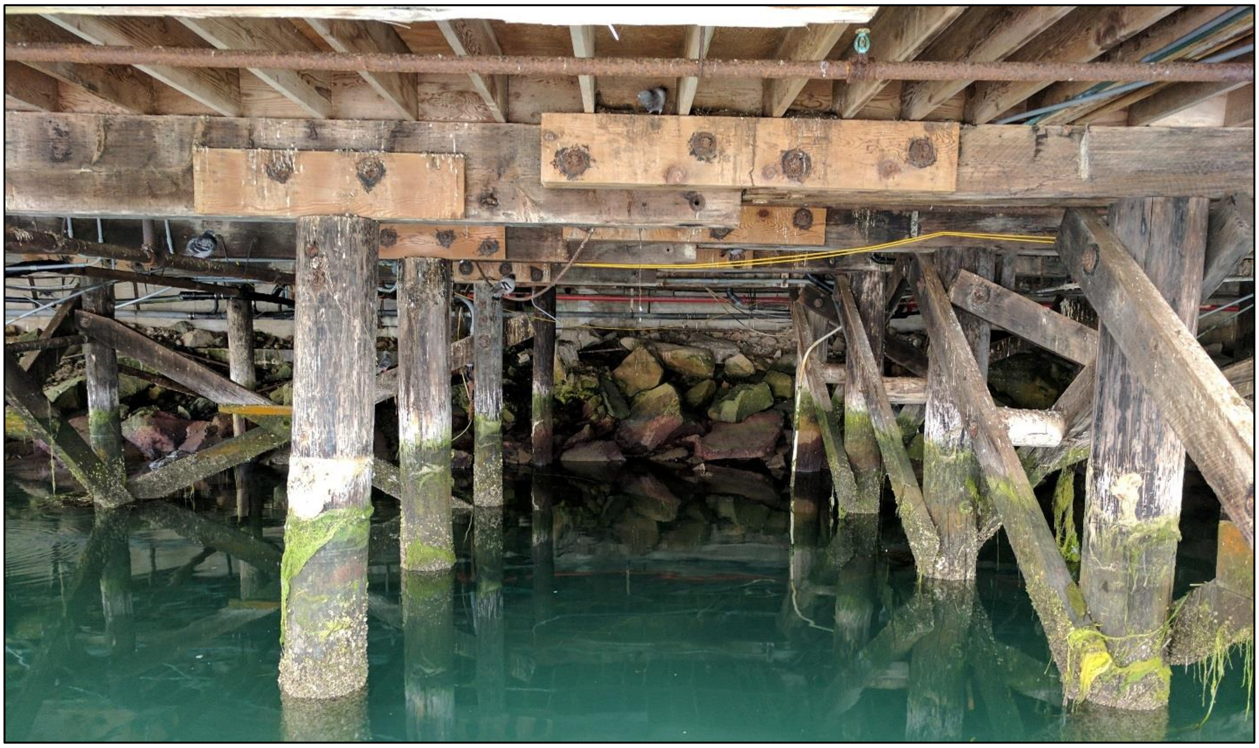


PHOTO 9. UNDER DECK UTILITIES

PHOTO 10. FLOATING PIER AND GANGWAY SYTEM AT THE EMBARCADERO WATERFRONT

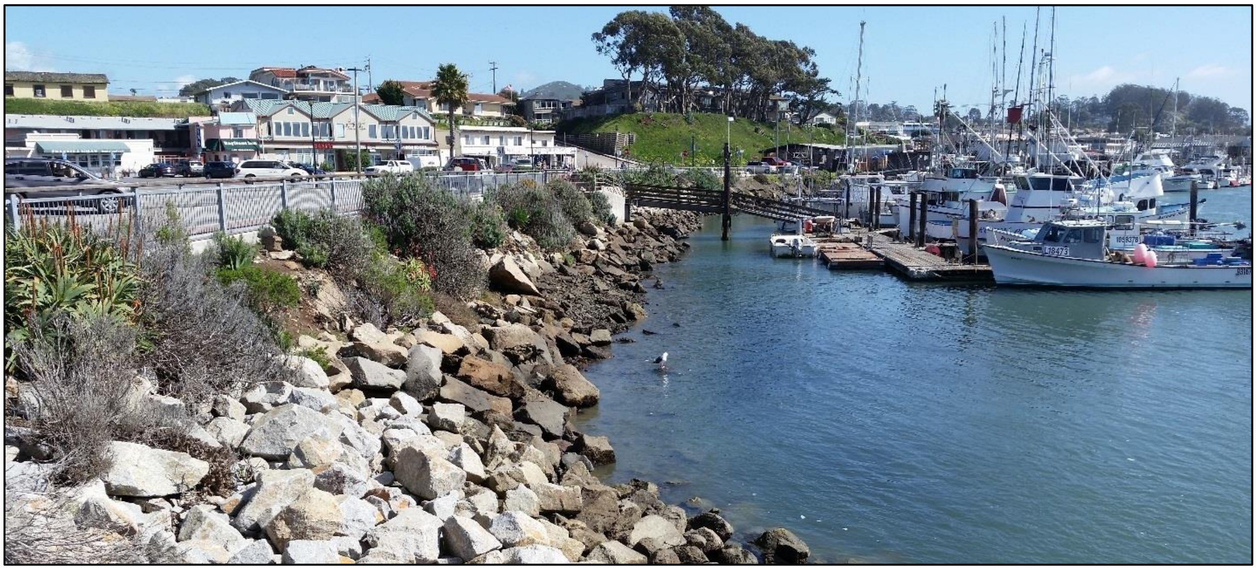


PHOTO 11. SHORELINE PROTECTION AT THE EMBARCADERO WATERFRONT

PHOTO 12. PUBLIC DOCKS

PHOTO 13. STORM DRAIN OUTFALL ALONG THE EMBARCADERO

The Embarcadero rests at a high enough elevation to endure significant amounts of SLR. A summary of findings from the vulnerability assessment, as described in the CBA, are as follows:

- Inundation Hazards – Under the 2050 high SLR scenario, utilities, floating docks, and storm drains may begin to encounter functionally debilitating flooding and high water issues. Under the 2100 high SLR scenario, these same assets will be fully vulnerable to tidal inundation and the Embarcadero as a whole will see water levels approaching roadway elevations (Figure 4-3). The OPC-SAT (2017) H++ scenario for SLR would raise daily tidal levels above the Embarcadero waterfront's existing grade.

- Flooding Hazards – Short-term, episodic flooding of the Embarcadero would be driven by precipitation events. If storm water outlets are inundated, nuisance flooding could result. The extent of this vulnerability was not analyzed as part of this study.

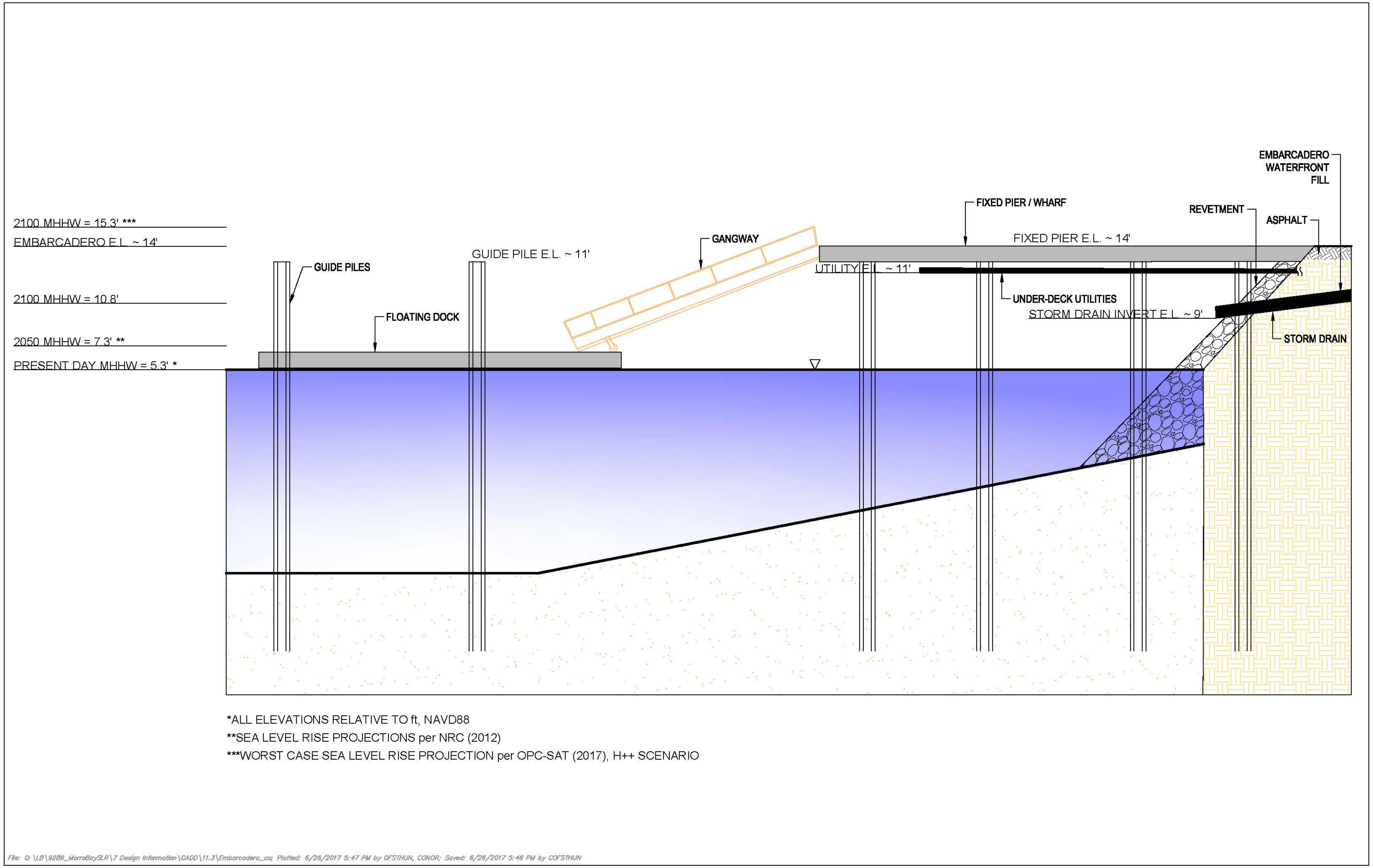


FIGURE 4-3. COASTAL HAZARDS IN THE EMBARCADERO WATERFRONT STUDY AREA

5. Adaptation Alternatives & Phasing Analysis

This section presents several potential adaptation alternatives for each of the study areas. Alternatives presented are not a comprehensive list, but rather present a variety of adaptation strategies that range from protection to retreat. A description of each alternative, as well as a discussion of the potential primary and secondary impacts is provided. These impacts as well as initial and life-cycle costs are summarized in tables provided for each site.

Phasing strategies for each of the three sites are also presented in this section. Each phasing strategy considers triggers that will mark the need for implementation of an action. For simplicity and practicality, triggers are associated with objective events, such as flooding and damage of an asset for this study. Phasing strategy diagrams are provided that associate triggers with levels of SLR; however, these points in time are currently hypothetical. Further coordination efforts with stakeholders and the community is needed to define when and how the City responds to future flooding and damage.

The phasing strategies presented in this section are divided into scenarios that represent considerably different approaches to SLR adaptation, motivated by triggers, and implemented in steps. Alternatives and phasing can be combined in multiple ways to address the goals of the City, stakeholders, and the community.

5.1. Highway 1

5.1.1. Highway 1 Adaptation Alternatives Analysis

Adaptation options for Highway 1 include various protection, accommodation, and retreat strategies. See Table 3-3 for a summary of adaptation costs and assumptions. These options are presented in this section.

5.1.1.1. Protect – Improve Existing Revetment

Revetments can be used to stabilize erodible slopes by providing rock armor layers able to resist wave energy forces. The existing Highway 1 revetment could be extended northward to provide bluff stability and protection from wave runup along this vulnerable segment. A revetment extension would span the area between the existing revetment and the Chevron bulkhead wall, and the area between the Chevron bulkhead wall and the Toro Creek Bridge.

Under high SLR projections the existing revetment crest becomes too low to provide adequate protection against wave overtopping and flooding. This is anticipated to occur prior to year 2050. A second adaptive step to protect the highway from an improved revetment would be to raise the crest of the extended revetment. A site-specific analysis would be needed to determine the height the revetment needs to be raised to meet the required level of protection.

The significant pros of improving the existing revetment include:

- Protection of the highway from current and future coastal hazards with no changes to Highway 1.
- Use of a known, relatively inexpensive shoreline protection measure.
- The City could implement this alternative with less Caltrans coordination than realignment or retreat alternatives.

The significant cons of this alternative include:

- Loss of beach habitat and recreational beach area as sea level rises as a result of a "coastal squeeze" between the ocean and the revetment.
- Regulatory permitting may be challenging for hard forms of shoreline protection.
- The revetment function will decrease as sea levels rise and will require periodic maintenance.
- Beach nourishment will likely be needed if the City wishes to maintain continuous public access along the beach in this area as sea levels rise.

5.1.1.2. SOFT PROTECTION – BUILD SAND DUNE

A soft solution for protection of Highway 1 is the construction of a sand dune as an "extension" of the existing sand dunes to the north. The dune would be built atop the existing revetment, creating a green/gray "living shoreline" type solution.

The significant pros of this alternative include:

- The dune would provide an inexpensive form of coastal protection to the highway and would provide a natural buffer for Highway 1 from wave run-up.
- The revetment core would provide a last line of defense for the highway should a storm event damage the dune in the areas where the revetment exists.
- The City could implement this alternative with less Caltrans coordination than realignment or retreat alternatives.
- Dunes could provide an opportunity to introduce a native habitat area. Vegetated dunes serve the benefit of being more stable than unvegetated dunes.

The significant cons of this alternative include:

- No specific design guidance exists for the use of dunes for shoreline protection on the west coast. Thus, the level of protection provided by the dune is unknown and is best implemented with an adaptive management plan in place.
- The dune may require frequent maintenance, especially as sea level rises.
- Creation of a dune habitat area would remove a portion of recreational beach area.

5.1.1.3. ACCOMMODATE – ELEVATE HIGHWAY ON BRIDGE

The vulnerable area of Highway 1 could accommodate SLR by extending the existing Toro Creek Bridge to the south. This option would construct new twin bridges to each carry two traffic lanes and shoulders. These bridges would likely be comprised of either cast-in-place concrete slabs or box girders, and supported on deep foundations. The structures would essentially be constructed at grade, then, over time as the bluff erodes, the bridge piers would be slowly exposed resulting in elevated structures.

The significant pros of this alternative include:

- The roadway elevation will be sufficient to remove highway vulnerabilities to coastal flooding and bluff erosion.

- The existing revetment would be removed, returning the area to natural dunes and bluffs.
- Beach widths would migrate landward but sandy beach should be maintained.

The significant cons of this alternative include:

- The beach would eventually erode to a point where the shoreline would be under the bridge, which would limit public access. This impact would not be anticipated without extreme rates of SLR.
- Bridge costs significantly exceed that of other alternatives.
- Highway 1 is owned and operated by Caltrans. Thus, the City does not have the ability to implement this alternative without coordination with Caltrans.

5.1.1.4. Retreat – Shift Alignment Eastward

This alternative would realign Highway 1, 20 to 180 ft east of its existing alignment starting at Toro Creek Bridge and extending 2,600 ft south. Realignment of Highway 1 NB and SB lanes within the City's jurisdiction is infeasible due to roadway geometry codes regarding adequate turning radii. The road would connect to the existing Highway 1 alignment just north of Morro Bay residential neighborhoods.

The significant pros of this alternative include:

- The roadway elevation and landward re-alignment should be sufficient to remove highway vulnerabilities to coastal flooding and bluff erosion through year 2100.
- Would provide a maximum of 180 ft of horizontal retreat (at the elbow of existing Highway 1).
- Could remove the existing revetment in all locations except where rock is needed for the Toro Creek southern bridge abutment, returning the area to natural dunes and bluffs.
- There would be greater space between the roadway and the ocean; thus, reducing the "coastal squeeze" effect through the study area likely beyond 2050. Beach widths would migrate landward but sandy beach should be maintained.

The significant cons of this alternative include:

- This alternative would only provide a minimum of about 20 ft of horizontal retreat (south of the Chevron bulkhead wall).
- The proposed alignment is outside of the City's jurisdiction. An agreement with the County of San Luis Obispo would be needed.
- Highway 1 is owned and operated by Caltrans. Thus, the City does not have the ability to implement this alternative without coordination with Caltrans.

TABLE 5-1. HIGHWAY 1 – ALTERNATIVES SUMMARY

Criteria	Status Quo	Protect		Accommodate	Retreat
		Revetment Improvements	Soft Protection	Elevate Road on Bridge	Shift Alignment Eastward
Description	Maintain revetment and roadway in place. Repair and maintain highway and rock revetment, as needed.	1. Construct a total 600 lf of new revetment with a crest elevation of 22 ft NAVD88. 2. Raise 1,150 ft of revetment by approximately 3 ft (25 ft NAVD88). Revetment would have 2:1 slopes and approximately 1,500 tons of 3- to 5-ton rock. These alternatives will hold the line to protect Highway 1.	A 1,150 lf vegetated sand dune would be constructed atop the existing revetment, creating a green/gray “living shoreline” type solution. Approximately 40,000 cy of material could build a 15-ft tall and 65-ft wide dune. Imported sand is assumed to “piggy-back” on the USACE annual harbor dredging activity. Three booster stations would be required to transport sand approximately 3 miles north from the harbor to Highway 1.	Construct two, 2-lane bridges totaling 70 ft in width, along 1,350 lf of highway. The 100,000-sf bridge would connect to the existing Toro Creek Bridge.	Shift Highway 1 eastward. Construct approximately 2,600 lf of new 2-way, 2-lane road. This alternative provides a maximum of 180 ft of horizontal retreat, south of the Chevron bulkhead wall. Existing revetment would be removed in all areas except near Toro Creek Bridge.
Transportation Impacts	More frequent and severe flooding of the roadway, resulting in delays and road closures. Roadway may become unstable if revetment is damaged.	Beneficial impacts of maintaining existing traffic configuration. Prevent wave overtopping and highway undermining.	Beneficial impacts of maintaining existing traffic configuration. Flood protection of roadway if dune is sized adequately.	Beneficial impacts of maintaining existing traffic configuration while adapting to SLR.	Beneficial impacts of maintaining existing traffic configuration while adapting to SLR.
Visual Impacts	Passive beach and bluff erosion could be exacerbated in medium- to long-term due to coastal squeeze between ocean and revetment and would reduce beach width. Should revetment and road be maintained, no infrastructure visual impacts should arise.	Raising revetment may result in loss of views of the ocean and beaches. Revetment slope results in loss of natural bluff and dune aesthetic.	Beneficial impacts to natural and aesthetic resources as dune habitat is formed.	Benefits as the bluff is returned to natural conditions if revetment is removed.	Possible beneficial aesthetic impacts as driver elevation is increased, increasing ocean views.
Environmental Resource Impacts	Passive beach and bluff erosion could be exacerbated. Loss of beach results in habitat loss.	Passive beach erosion could be exacerbated in medium- to long-term (if not combined with frequent nourishment) due to revetment footprint occupying beach, and potentially from waves impacting the revetment. Loss of beach results in habitat loss.	A vegetated sand dune provides increased habitat.	Beaches maintained as the bluff erodes and the beach is allowed to migrate landward, potentially retreating under the bridge.	Removal of existing revetment would return approximately 550 lf of bluff to natural conditions. Beach widths likely would be maintained as the bluff erodes and the beach can migrate landward.
Public Access Impacts	No change to existing vertical beach access point. Moderate to significant impacts for horizontal access along the beach; assuming revetment is maintained, erosion will result in a narrow beach.	No change to existing vertical beach access point. Moderate to significant impacts for horizontal access along the beach; assuming hard protection occurs alone, erosion will result in a narrow beach.	No change to existing vertical beach access point. Horizontal access is maintained except for some loss of towel space where sensitive vegetation is anticipated to root.	No change to existing vertical beach access point. Horizontal access is maintained until beach erodes underneath the bridge.	No change to existing vertical beach access point. Horizontal access is maintained.
Sea Level Rise Resiliency over Design Life	Low to Moderate – Existing revetment will protect roadway from existing coastal hazards and some level of SLR. Increased water levels will result in more frequent overtopping and may undermine the roadway.	High – Will protect roadway from increased flooding and erosion due to SLR.	Moderate – Dune construction would provide a moderate buffer to SLR. However, major storms and extreme SLR scenarios would likely damage the dune. Frequency and volume of maintenance will need to increase as sea levels increase.	High – The roadway would be designed to avoid all potential SLR scenarios.	Moderate to High – An inland alignment should provide sufficient elevation and setback distance to withstand high SLR projections. Portion of highway near Toro Creek Bridge would become most vulnerable to SLR.

Criteria	Status Quo	Protect		Accommodate	Retreat
		Revetment Improvements	**Soft Protection**	**Elevate Road on Bridge**	**Shift Alignment Eastward**
Approximate Design Life*	Increased vulnerability w/time.	25 years	~ 20 to 40 years Maintenance of ½ the total dune volume assumed necessary every 5 years. Feasibility study required.	75 years	~75 years. However, the area south of Toro Creek Bridge and around the Chevron bulkhead wall are anticipated to need additional protection within the 75 year timeframe.
Initial Cost (USD)**	$0	Extend Revetment = $1.5M Raise Revetment = $300K	$640K	$15 to $30M	$5.3M
20-Year Lifecycle Cost (USD)***	$330K	$700K****	$2.0M	$50K	$100K to maintain revetment near Toro Creek

**Design life considers life span w/respect to SLR and life span w/respect to normal wear and tear. The number presented represents the shortest of the two (i.e., more conservative).*
***Preliminary order of magnitude cost, see Table 3-3 for assumptions and unit costs considered for this estimate.*
****Includes cost of maintenance. Does not include initial costs.*
***** Repair costs are assumed unchanged whether revetment is raised or not raised.*

5.1.2. Highway 1 Phasing Strategy

Three scenarios are proposed for Highway 1 that consist of protection and horizontal and vertical retreat options. These strategies are described below.

5.1.2.1. Scenario 1 - Protect

Currently, Highway 1 is not in danger of severe damage or functional failure; thus, **No Action** will take place in the immediate term until roadway damage and flooding exceeds the City's or Caltrans' tolerance of risk or becomes financially burdensome to maintain. At that time, the first **trigger** would be met and **Step 1** would be initiated. This step consists of constructing a vegetated sand dune. The sand dune will begin at Toro Creek to the north and end at the existing bluff to the south.

As sea levels continue to rise, the dune may become overtopped and eroded, leading to roadway flooding and damage. At this point, the next **trigger** would be met and the City or Caltrans would implement **Step 2**, which is to extend the existing revetment to protect this entire vulnerable reach of roadway. After the revetment extension, sand could be placed on top, creating a sand dune with a revetment core.

Wave overtopping and undermining of the revetment will be the **trigger** for **Step 3**, which is to raise the entire revetment to protect against year 2100 SLR.

Scenario 1 has the benefit of phasing in a variety of adaptive measures over time, starting with soft solutions and transitioning into soft/hard solutions. See Figure 5-1**Error! Reference source not found.** for a depiction of Scenario 1. An implementation timeline for this scenario is illustrated in Figure 5-4**Error! Reference source not found.**.

5.1.2.2. Scenario 2 – Horizontal Retreat

Under Scenario 2, **No Action** is warranted until the roadway begins to become undermined or flooded during extreme events as the first **trigger**. At this time, **Step 1** would begin. The City and Caltrans would begin the planning process to realign the roadway to the east. Re-alignment will require roadway construction outside of the City limits, tying in to the Toro Creek Bridge to the north. Under this scenario, the existing revetment will be removed and the highway will rely on the abandoned land as a natural buffer for protection.

Scenario 2 has the benefit of retreating from coastal hazards and restoring the natural condition of the bluff and beach. See Figure 5-2**Error! Reference source not found.** for a depiction of Scenario 2. An implementation timeline for this scenario is illustrated in Figure 5-4**Error! Reference source not found.**.

5.1.2.3. Scenario 3 – Vertical Retreat

Under Scenario 3, **No Action** is warranted until the roadway begins to become undermined or flooded during extreme events as the first **trigger**. If this occurs, **Step 1** would begin. The City or Caltrans would begin the planning process to raise the roadway on a bridge. Under this scenario, the existing revetment will be removed, allowing erosion and SLR to continue naturally under the raised roadway. See Figure 5-3**Error! Reference source not found.** for a depiction of Scenario 3. An implementation timeline for this scenario is illustrated in Figure 5-4**Error! Reference source not found.**.

FIGURE 5-1. HIGHWAY 1 – SCENARIO 1

FIGURE 5-2. HIGHWAY 1 – SCENARIO 2

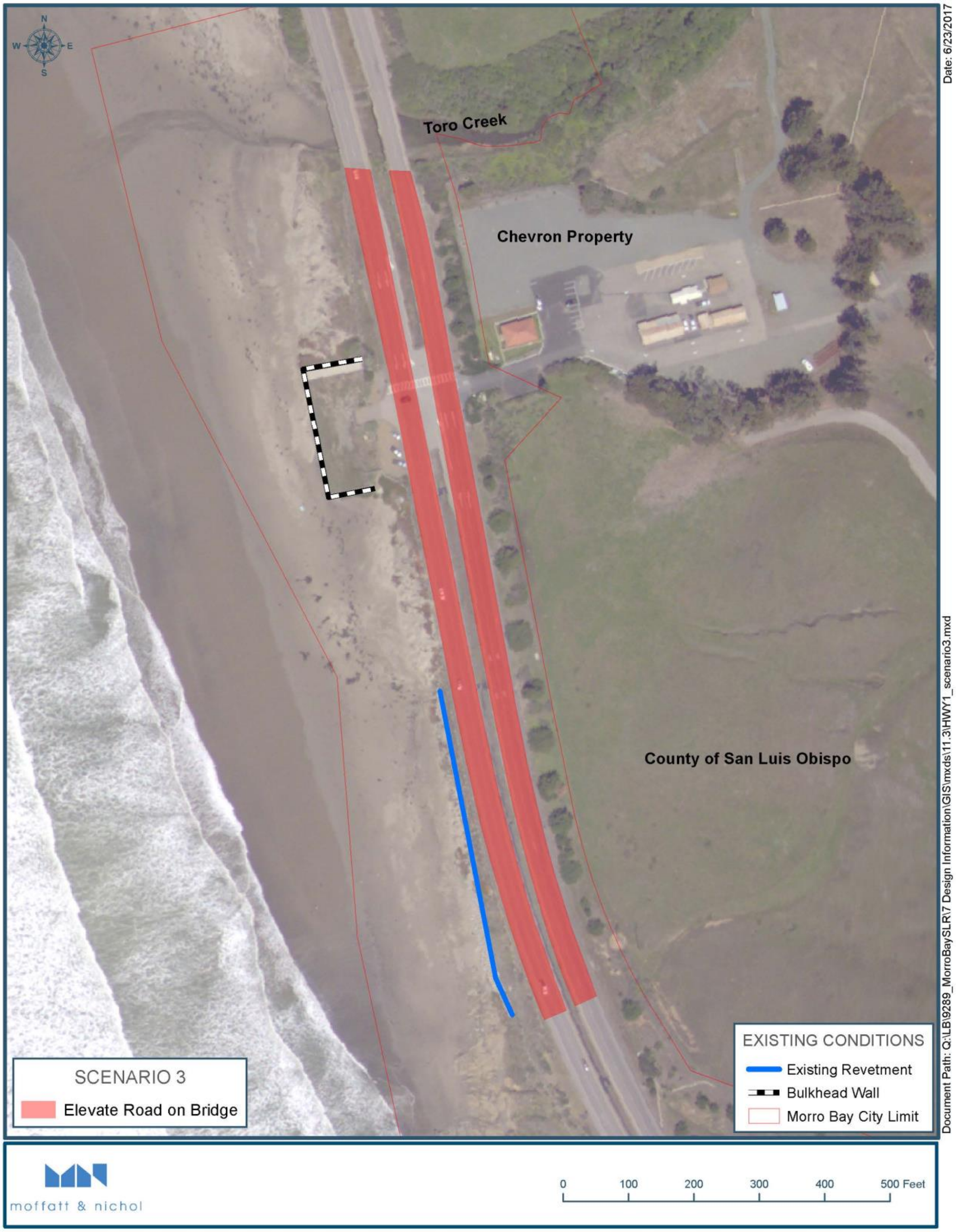


FIGURE 5-3. HIGHWAY 1 – SCENARIO 3

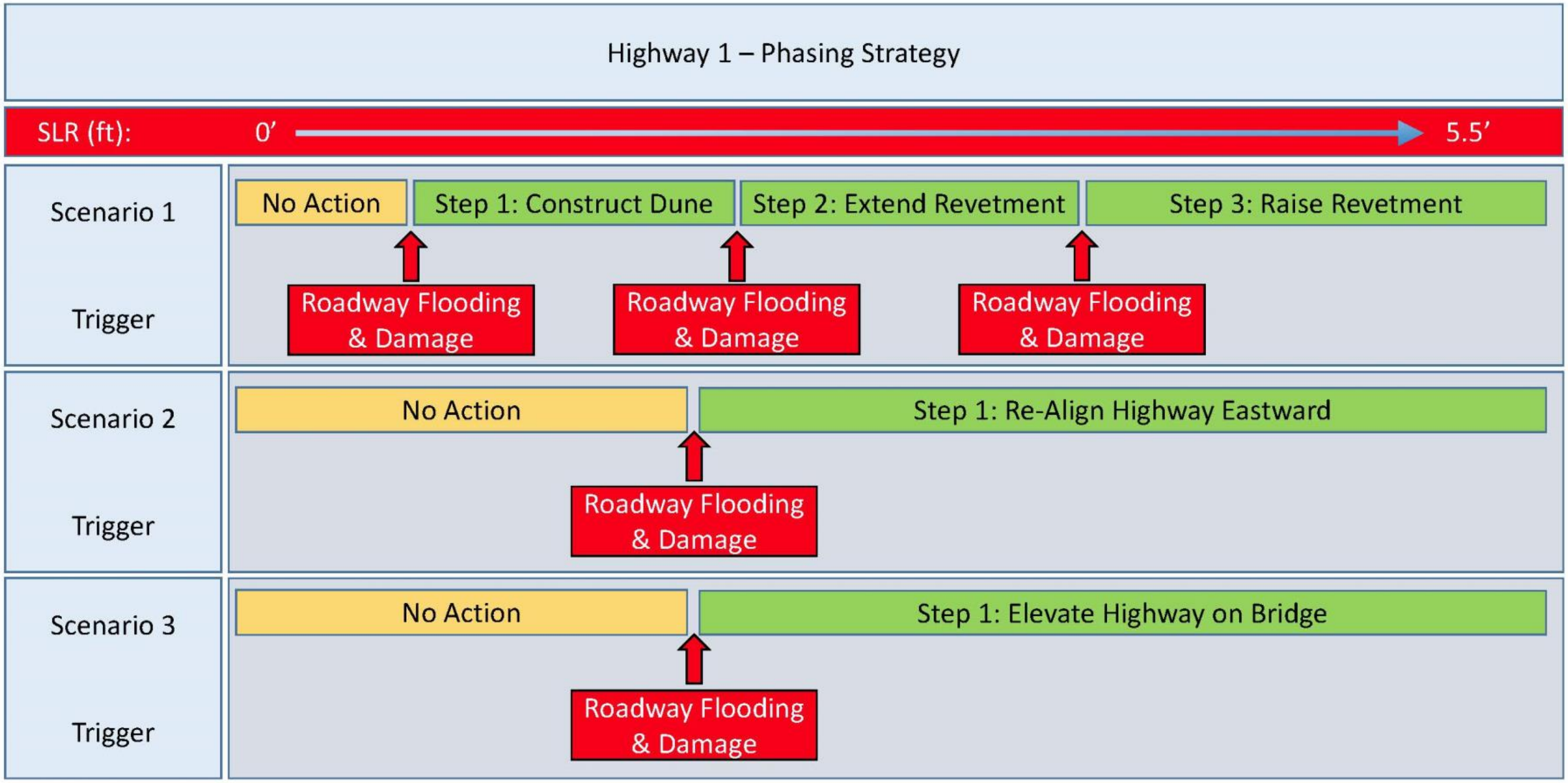


FIGURE 5-4. HIGHWAY 1 - PHASING STRATEGY

5.2. MORRO ROCK PARKING LOT

5.2.1. MORRO ROCK PARKING LOT ADAPTATION ALTERNATIVES ANALYSIS

Adaptation options for Morro Rock parking lot include various hybrid collections of protection, accommodation, and retreat strategies. These options are presented in this section.

5.2.1.1. PROTECT & RETREAT – RE-ALIGN AND RAISE EXISTING REVETMENT

The existing revetment would be re-aligned by retreating it southward between 110 and 180 feet. The re-alignment would begin at the Dynegy ocean outfall and end at the bike path. The revetment could later be fortified and raised by adding additional rock to provide additional protection against erosion and flooding. The parking lot surface could either remain below the revetment crest for protection from wave runup, or could be raised with the revetment crest to reduce its vulnerability.

The significant pros of this alternative include:

- Raising the revetment would protect the parking lot against modest rates of SLR. More detailed engineering efforts are needed to determine an appropriate revetment design to protect the parking lot through a given planning horizon.
- Re-aligning the revetment would provide more recreational beach and beach habitat area, reducing the coastal squeeze between the ocean and the structure.

The significant cons of this alternative include:

- Regulatory permitting may be challenging for hard forms of shoreline protection.
- Coastal squeeze will occur as sea levels rise.
- Maintenance of the revetment will be needed over time to repair damage and to add rock to the structure.

5.2.1.2. SOFT PROTECTION – CONSTRUCT SAND DUNE

A soft solution for protection of the Morro Rock parking lot is the construction of a sand dune created as an "extension" of the existing sand dunes to the north. The dune would be built atop the existing revetment, creating a green/gray hybrid "living shoreline" type of solution.

The significant pros of this alternative include:

- The dune would provide a natural buffer for Morro Rock parking lot from wave run-up and erosion.
- The revetment core would provide a last line of defense should a storm event damage the dune.
- Planting native plants would provide increased stability of the dune while also providing habitat area. Dunes may be considered an improved aesthetic from the community.

The significant cons of this alternative include:

- The sand dune would likely need periodic maintenance in the form of dune re-nourishment. Sand for this maintenance could be derived from the annual USACE dredging program.

- Blowing sand from the created dune may result in maintenance of the parking lot to remove sand. Sand fencing along the dune or native dune vegetation could reduce this maintenance need.

- No specific design guidance exists for the use of dunes for shoreline protection on the west coast. Thus, the level of protection provided by the dune is unknown and is best implemented with an adaptive management plan in place.

- The dune may require frequent maintenance, especially as sea level rises.

- Creation of a dune habitat area would remove a portion of recreational beach area.

5.2.1.3. Accommodate & Retreat – Elevate Parking Lot

To accommodate SLR, the Morro Rock parking lot would be retreated 80 feet south of the existing revetment and grades would be raised 6 to 8 ft. The parking lot would be paved and parking would be formalized through striping. The abandoned land seaward of the raised parking lot could be used for various forms of passive recreation.

The significant pros of this alternative include:

- Retains the existing land mass that serves to protect navigational, commercial, and recreational uses of Morro Bay harbor.

- Can accommodate high SLR rates by raising existing grades at Morro Rock parking lot.

- Parking lot retreat and improvements can provide recreational amenities for the community.

- SLR accommodation improvements to the parking lot can open up opportunities for creativity in the redevelopment of Morro Rock parking lot.

The significant cons of this alternative include:

- Coordination will be needed between the City and California State Parks as jurisdictional lines in this area are complex. The General Plan/LCP Update requires that a future Master Plan be prepared for this area. This planning document would capture navigational and parking goals and requirements of this area. The General Plan/LCP will set the framework for what the Master Plan needs to accomplish.

- Coastal squeeze between the ocean and the revetment will occur as sea levels rise. This would result in decreased coastal habitat and recreational area.

TABLE 5-2. MORRO ROCK PARKING LOT - ALTERNATIVES SUMMARY

Criteria	Status Quo	Protect		Accommodate / Retreat
		Revetment Improvements	Soft Protection	Parking Improvements
Description	Maintain 1,000 ft of revetment. Repair and maintain parking lot as needed.	Two options to hold the line to protect parking: 1. Re-align the 1,000 ft existing revetment. At the inland end of the Dynegy outfall revetment, begin the re-alignment of the new revetment, end the revetment at the bike path on the east side of the parking lot. New revetment is assumed to be 650 x 34 x 8 ft (L x W x H), or 10,000 tons. Provides a range of approximately 110-180 ft of horizontal retreat. 2. Raise the re-aligned revetment by 5 ft (21 ft NAVD88). Revetment would have 2:1 slopes and require approximately 2,000 tons of additional 3- to 5-ton rock.	A 650 lf vegetated sand dune could be created as an "extension" of the existing sand dunes to the north. Approximately 25,000 cy of material could build a 15-ft tall and 65-ft wide dune. The dune would be built atop the revetment, creating a green/gray "living shoreline" solution. Imported sand is assumed to "piggy-back" on the USACE's annual harbor dredging activity.	Pull back parking from the revetment and raise the parking lot by 6-8 ft to an elevation of approximately 22-24 ft NAVD88. This elevated parking platform provides approximately 80 ft of horizontal retreat. Formalize parking stalls to promote efficient use of smaller parking space. 170 parking spaces would be striped within the 80,000-sf raised platform.
Visual Impacts	No visual impacts would result from maintaining the existing condition.	Moderate aesthetic impacts to beach users from raised revetment that would partially obstruct existing ocean views from parking lot.	Beneficial impacts to natural and aesthetic resources as dune habitat is formed.	Beneficial impacts to ocean views from the raised parking lot.
Environmental Resource Impacts	Passive beach erosion could be exacerbated in medium- to long-term due to coastal squeeze between ocean and revetment. Beach loss impacts.	Passive beach erosion could be exacerbated in medium- to long-term (if not combined with frequent nourishment) due to revetment footprint occupying beach, and potentially from waves impacting the revetment.	A vegetated sand dune provides habitat.	Passive beach and dune erosion could be exacerbated in medium- to long-term due to coastal squeeze between ocean and revetment.
Public Access Impacts	Interruptions to public use are expected to increase as water levels increase.	Public access to the beach would be limited to fixed points along the revetment, similar to existing condition. Public access along the beach could be impacted in long- term.	No change to pedestrian beach access. Beneficial impacts of reduced parking lot flooding.	Added walking distance from standard parking to beach. In the long-term, beach access is maintained by raising the parking lot above hazardous SLR and storm scenarios.
Sea Level Rise Resiliency over Design Life	Low to Moderate – The existing revetment will protect parking lot from existing coastal hazards and possibly some level of SLR. Increased water levels will flood and erode the parking lot more frequently.	High – Will protect parking lot from increased erosion and flooding due to SLR.	Moderate – Dune construction would provide a moderate buffer to SLR. However, major storms and extreme SLR scenarios would likely damage the dune. Frequency and volume of maintenance will need to increase as sea levels increase.	High – The parking lot can be raised to withstand high SLR projections. The existing revetment may require fortification to protect the parking lot from erosion.
Approximate Design Life*	0-30 Years. Increased vulnerability with time.	25 years	20 to 40 years Maintenance of ½ the total dune volume assumed necessary every 5 years. Feasibility Study Required.	30 years
Initial Cost (USD)**	$0M	Re-Align Revetment = $900K Raise Revetment = $400K	$250K	$800K
20-Year Lifecycle Cost (USD)***	$600K	$400K	$500K	$0

**Design life considers life span w/respect to SLR and life span w/respect to normal wear and tear. The number presented represents the shortest of the two (i.e., more conservative).*
***Preliminary order of magnitude cost, see Table 3-3 for assumptions and unit costs considered for this estimate.*
****Includes cost of maintenance. Does not include initial costs.*

5.2.2. MORRO ROCK PARKING LOT PHASING STRATEGY

Two scenarios are proposed for the Morro Rock parking lot. These strategies are described below.

5.2.2.1. SCENARIO 1 – RAISE REVETMENT AND RAISE & RETREAT PARKING

No Action will take place until the frequency and damage of the parking lot from coastal storms becomes financially burdensome or unacceptable to the public. After this **trigger**, **Step 1** would be to raise the existing revetment in place. Final revetment design would be determined by the existing and projected conditions at the time of the trigger. The raised revetment would protect the parking lot for some time determined by engineering design.

As sea levels continue to rise, the parking area will become increasingly vulnerable to flooding and damage. After this **trigger**, **Step 2** would be to retreat and raise the parking lot southward. This retreat will maintain use of the existing parking lot, but will reconfigure parking away from the ocean and elevate the parking lot above flood levels. The abandoned area between parking and revetment could become a passive recreation area. This scenario "holds the line" of the existing revetment fronting Morro Rock parking lot as sea level rises. See Figure 5-5**Error! Reference source not found.** for a depiction of Scenario 1. An implementation timeline for this scenario is illustrated in Figure 5-7**Error! Reference source not found.**.

5.2.2.2. SCENARIO 2 – RETREAT & RAISE PARKING, CONSTRUCT DUNE, AND RE-ALIGN & RAISE REVETMENT

No Action will take place until the frequency and damage of the parking lot from coastal storms becomes financially burdensome or unacceptable to the public, the first **trigger**. At this time, planning and permitting for the raised parking lot adaptation is recommended. **Step 1** would be to retreat and raise the parking lot southward. This retreat will maintain use of the existing parking lot, but will reconfigure parking away from the ocean and elevate the parking lot above flood levels. The abandoned area could become a temporary passive recreation area. Flooding and damage of the temporary passive recreation area would **trigger Step 2**. At **Step 2**, a sand dune would be constructed seaward of the raised platform to provide a living shoreline form of coastal protection.

As sea level rises, the dune may become overtopped and erode, the existing revetment may fail, and overtopping may reach the raised parking lot. After this **trigger**, the City would initiate **Step 3**, which would be to re-align and raise the existing revetment. The revetment would be moved closer to the raised parking and be buried by the reconstructed vegetated dune, acting as a revetment core to provide a last line of defense against year 2100 or higher SLR projections.

This scenario combines three solutions to maintain harbor channel navigation, improve Morro Rock parking lot protection, upgrade recreational facilities, increase recreational beach area, and improve habitat for native species. See Figure 5-6**Error! Reference source not found.** for a depiction of Scenario 2. An implementation timeline for this scenario is illustrated in Figure 5-7**Error! Reference source not found.**.

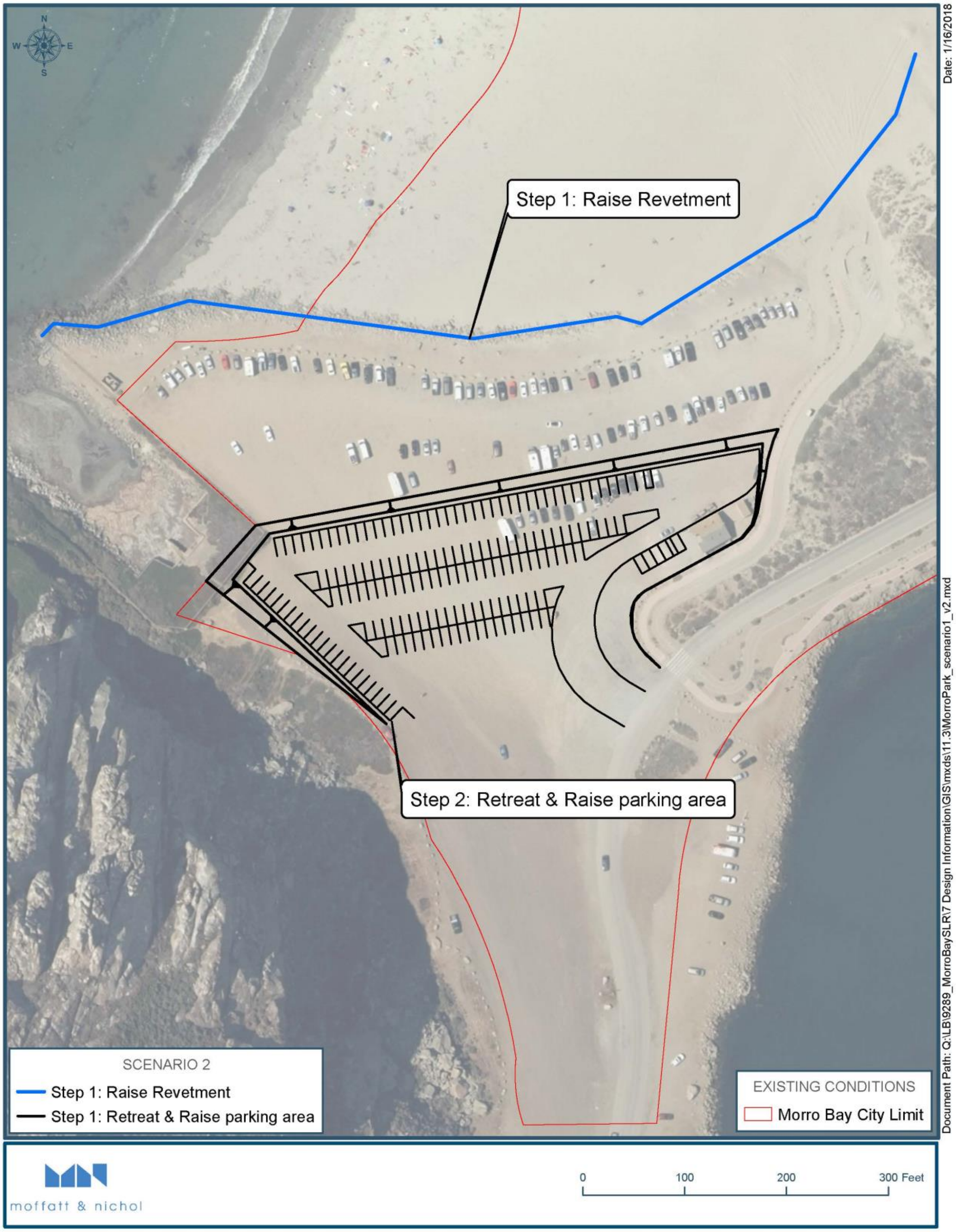


FIGURE 5-5. MORRO ROCK PARKING LOT – SCENARIO 1

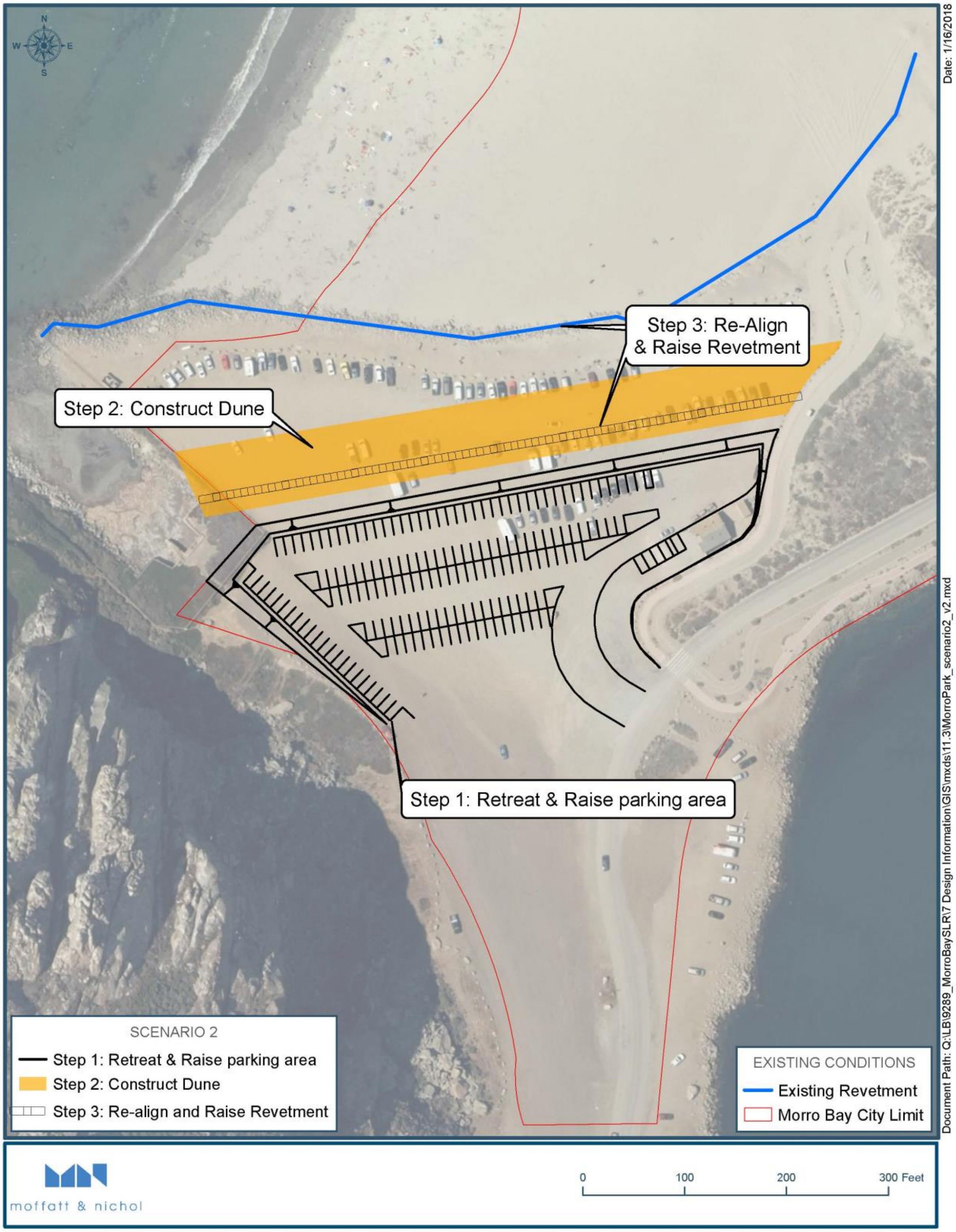


FIGURE 5-6. MORRO ROCK PARKING LOT – SCENARIO 2

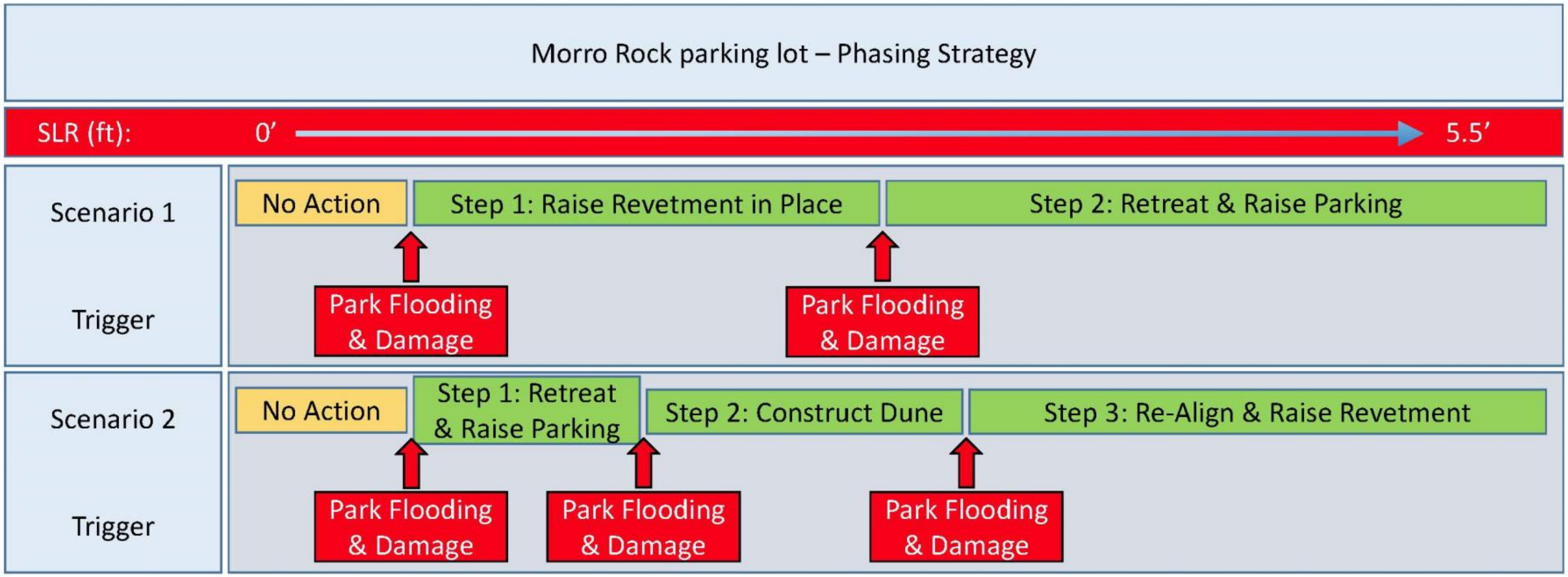


FIGURE 5-7. MORRO ROCK PARKING LOT – PHASING STRATEGY

5.3. EMBARCADERO WATERFRONT ALTERNATIVES ANALYSIS

5.3.1. EMBARCADERO WATERFRONT ADAPTATION ALTERNATIVES ANALYSIS

Adaptation options for the Embarcadero waterfront study area are mostly focused on accommodation since the waterfront and supporting facilities have significant elevation. However, extreme SLR estimates (i.e., 10 ft) would result in a host of vulnerabilities. A vertical retreat option is presented to adapt to such a scenario. These options are presented in this section.

5.3.1.1. ACCOMMODATE – UTILITY IMPROVEMENTS

Two existing piers along the Embarcadero waterfront study area are fixed in-place with a platform elevation of approximately 14 ft, NAVD88. By year 2100, SLR is not predicted to inundate the fixed piers. However, underdeck utilities along the Embarcadero piers may be vulnerable to daily wetting and drying because of SLR. Wetting and drying of utilities can cause the design lives to reduce dramatically and will result in more rapid failures. The local community relies heavily on these coastal utilities, including recreational and commercial boaters.

In this adaptation option, vulnerable utilities would be improved to become more resilient to SLR. Utilities will require either reconfiguration, removal, and/or protection. Protection would involve waterproofing exposed wires and connections. Reconfiguration would involve relocating underdeck utilities to on-deck.

The significant pros of this alternative include:

- Low-cost adaptation measure that would maintain regular public and commercial function of the Embarcadero waterfront.
- Measures could be implemented slowly on an as-needed basis.

The significant cons of this alternative include:

- Required attentive monitoring to prevent issues (e.g., spills, outages).

5.3.1.2. ACCOMMODATE – FLOATING DOCK IMPROVEMENTS

Generally, floating dock guide piles reach a maximum elevation of approximately 11 ft NAVD88 in the study area. Guide pile issues could arise if extreme water levels cause floating docks to sit higher on the pile than designed. The floating dock could overtop the pile or it could exert a greater force (i.e., side-loading) on the pile during high current and wave scenarios. Timber guide piles typically have a lifespan of 25 years and concrete piles of 50 years. Under current SLR projections, it is highly likely the piles will need replacement before any functional issues begin. Therefore, come the end of a pile's lifespan, the replacement pile must be made to extend higher than the Embarcadero elevation, and be driven deep into the subsurface to ensure stability under high water level, current, and wave scenarios.

Should guide piles be tall enough to accommodate SLR, the gangway could encounter issues during high water level conditions. As the floating dock rises, the gangway will flatten out and will occupy a larger area of the dock. It is important that the dock space be managed to allow for the gangway to extend fully. In extreme SLR scenarios, and just before the Embarcadero is flooded, the gangway may rise high enough to result in an inverse slope (i.e., gangway slopes landward as opposed to seaward). Gangways are not typically designed to accommodate inverse slopes, or even level slopes. Modifications, such as replacing the gangway or creating a land-based ramp up, may be necessary to accommodate high SLR conditions.

The significant pros of floating dock improvements include:

- Adaptation measures would likely be implemented toward the end of a structures design life. Thus, no retrofitting costs would be incurred.
- Measures could be implemented slowly on an as-needed basis.

The significant cons of this alternative include:

- Attention is required during the approval of new facilities or lease renewals to ensure blanket standards are applied to leaseholds.

5.3.1.3. ACCOMMODATE – STORM DRAIN IMPROVEMENTS

A total of three storm drains exist along the Embarcadero Waterfront study area. Storm drain invert elevations are estimated at approximately 9 ft NAVD88. When water levels rise above outlet elevations, stormwater can back-up in pipes and may cause flooding of upland areas (sometimes referred to as nuisance flooding). Raising storm drain outlet elevations above projected SLR would allow the Embarcadero stormwater system to function during these conditions. Alternatively, the existing storm drain outlets could remain in place and be improved by the installation of rubber duckbill (or similar) check valves. Rubber duckbill check valves allow only one-directional flow, which would prevent the intrusion of seawater into storm drains when water elevations are above the outlet.

However, storm drain systems are only functional if sufficient head (i.e., pressure difference) exists between land-based flooding areas and the ocean. Should SLR result in water levels that are frequently above the storm drain invert elevation, backflow and upland flooding could occur. Under such circumstances, all or portions of the storm drain system within the Embarcadero study area would need to be raised. This would raise the low points of the storm drain system and restore invert elevations.

The significant pros of this alternative include:

- It is a lower-cost adaptation measure that would maintain function of the storm drain system and reduce nuisance flooding within the Embarcadero waterfront.
- Measures could be implemented on an as-needed basis.

The significant cons of this alternative include:

- Required attentive monitoring to prevent issues.

5.3.1.4. VERTICAL RETREAT – RAISE WATERFRONT

To adapt to the most extreme SLR estimates (i.e., 10 ft) a vertical raise of the waterfront land, piers, and supporting facilities would be needed. In this scenario, the roadways, parking, piers, and structures would be raised 5 ft to accommodate SLR. The vertical retreat of this area would not be an insignificant effort and could be implemented relatively quickly as part of a re-visioning/redevelopment project, or slowly as leases expire and parcels are improved.

The significant pros of this alternative include:

- Maintenance of regular public and commercial function of the Embarcadero waterfront under a very high SLR scenario for year 2100.

- Redevelopment of this land can be an opportunity for creative ideas for this area.

The significant cons of this alternative include:

- Implementing this strategy would be a large undertaking and logistically challenging (various leaseholds, funding, environmental impacts, etc.).
- Commercial and recreation along the Embarcadero waterfront would be significantly impacted during construction.

TABLE 5-3. EMBARCADERO WATERFRONT ALTERNATIVES SUMMARY

Criteria	Status Quo	Accommodate			
		Utility Improvements	Floating Dock Improvements	Storm Drain Improvements	Raise Waterfront
Description	Tenant repairs and maintains utilities, docks, storm drains, and other assets as needed and as leases are renewed.	Waterproof underdeck utilities (electric, water, sewer, gas) and/or relocate to on-deck.	When existing guide piles require replacement, install piles that vertically accommodate SLR. Drive pile deep enough to manage increased side-loading. Assumed 250 existing pier and dock piles. Ensure gangway hinges can accommodate a level or inverse slope (assumed 7 gangways). If not, replace existing gangway or raise the landing.	The existing storm drains could remain in place and be improved by the installation of check valves. Check valves allow only uni-directional flow, similar to flap gates. Check valves prevent the intrusion of seawater into storm drains, reducing backflow and protecting investments in upland storm water Best Management Practices (BMPs).	Roadways, parking, and structures would be raised 5 feet to accommodate SLR. Buildings could either be reconstructed and raised to meet new roadway elevations, or the first floor could be abandoned and utilities adapted to accommodate raising the Embarcadero.
Environmental Resource Impacts	Failure of systems results in spills and leaks.	Benefits of reduced sewage spills, and increased safety from electric and gas related hazards.	Temporary seabed impacts during guide pile construction.	No significant impacts.	Potential environmental impacts from construction. Seabed disruptions.
Visual Impacts	None	None	None	None	Direct impact from raised Embarcadero. May impact views from elsewhere in the city, including from private homes.
Public Access Impacts	Existing public access locations will remain in the near-term. Potential gangway, dock, and utility issues with rising water levels could disrupt public use.	None	Beneficial impacts to public use as floating dock functions accommodate SLR. Potential gangway issues as water levels approach gangway landing elevation.	Storm drain improvements would prevent backflow from SLR and storms, allowing continued public use of the Embarcadero.	No significant impacts assuming redeveloped waterfront maintains public access features throughout.
Sea Level Rise Resiliency over Design Life	Moderate – Generally the Embarcadero Waterfront is elevated outside of high sea level projection flood zones. Potential disruptions expected as water levels approach assets.	Moderate to High – Utility accommodation measures will increase the ability of the Embarcadero to endure SLR.	High – Floating dock accommodation measures will increase the ability of the Embarcadero to endure SLR.	Moderate to High – Storm drain accommodation measures will increase the ability of the Embarcadero to endure SLR.	High – Embarcadero could be raised to avoid highest SLR projections for year 2100.
Approximate Design Life*	The Embarcadero as a whole is resilient to flooding until year 2100 high SLR projections combined with MHHW. The Embarcadero is resilient to inundation until sea level rises 9+ ft.	Varies case by case.	Concrete guide piles = 50 years Gangways = 25 years	20 years	100 years
Initial Cost (USD)**	$0	< $100K	Replace 250 Concrete Guide Piles = $1.25M Replace 7 Gangways = $140K	$2-4K	>$100M
20-Year Lifecycle Cost (USD)***	Increased asset vulnerability with time.	< $100K	No anticipated maintenance or replacement within 20 years of construction.	Occasional Debris Removal	No change from current Embarcadero maintenance costs.

**Design life considers life span w/respect to SLR and life span w/respect to normal wear and tear. The number presented represents the shortest of the two (i.e,. more conservative).*
***Preliminary order of magnitude cost, see Table 3-3 for assumptions and unit costs considered for this estimate.*
****Includes cost of maintenance. Does not include initial costs.*

5.3.2. Embarcadero Waterfront Phasing Strategy

Two scenarios are proposed for the Embarcadero Waterfront study area. These scenarios are presented in this section.

5.3.2.1. Scenario 1 – Accommodate

Currently, the Embarcadero Waterfront is fully functional and **No Action** will take place. As sea level rises, issues may arise with respect to waterfront functions such as storm drains, utilities, and floating docks. Storm drains may back-up with water, resulting in flooding of upland areas. Utilities may be damaged or become hazards for gas leaks and electricity shortages. Floating docks may overtop guide piles, and gangways may be forced into positions beyond design. Should any of these areas suffer damage or dysfunction as a result of increased water levels, Step 1 will be **triggered**. **Step 1** will waterproof or relocate utilities above flood levels. It will improve storm drains with a duckbill check valve (or similar) to eliminate backflow and upland flooding during high flow and high water levels. Replace floating dock guide piles with stronger and taller replacements. Replace malfunctioning gangways or raise the landing area. Step 1 is not expected to be triggered until considerable SLR has taken place, potentially as early as 2050 and as late as beyond 2100, under NRC (2012) SLR predictions. However, the OPC-SAT (2017) worst case scenario provided the possibility that catastrophic SLR of 10 ft could occur by year 2100. Should this occur, regular flooding of the Embarcadero would **trigger Step 2**, the raising of all structures and grades. This action will likely prompt a major redevelopment plan from the City. Parking lots and roads, if left in place, would also need to be raised above water levels. See Figure 5-9 for a cross-section of the Embarcadero with approximate asset elevations and potential SLR elevations for reference. An implementation timeline for this scenario is illustrated in Figure 5-8.

5.3.2.2. Scenario 2 – Vertical Retreat

Under Scenario 2, **No Action** will occur until SLR issues arise with respect to waterfront functions such as storm drains, utilities, and floating docks. Backed up storm drains, electrical outages, and dysfunctional docks will **trigger Step 1**, the raising of all structures and grades. This will preemptively adapt the Embarcadero waterfront as a whole to SLR. An implementation timeline for this scenario is illustrated in Figure 5-8.

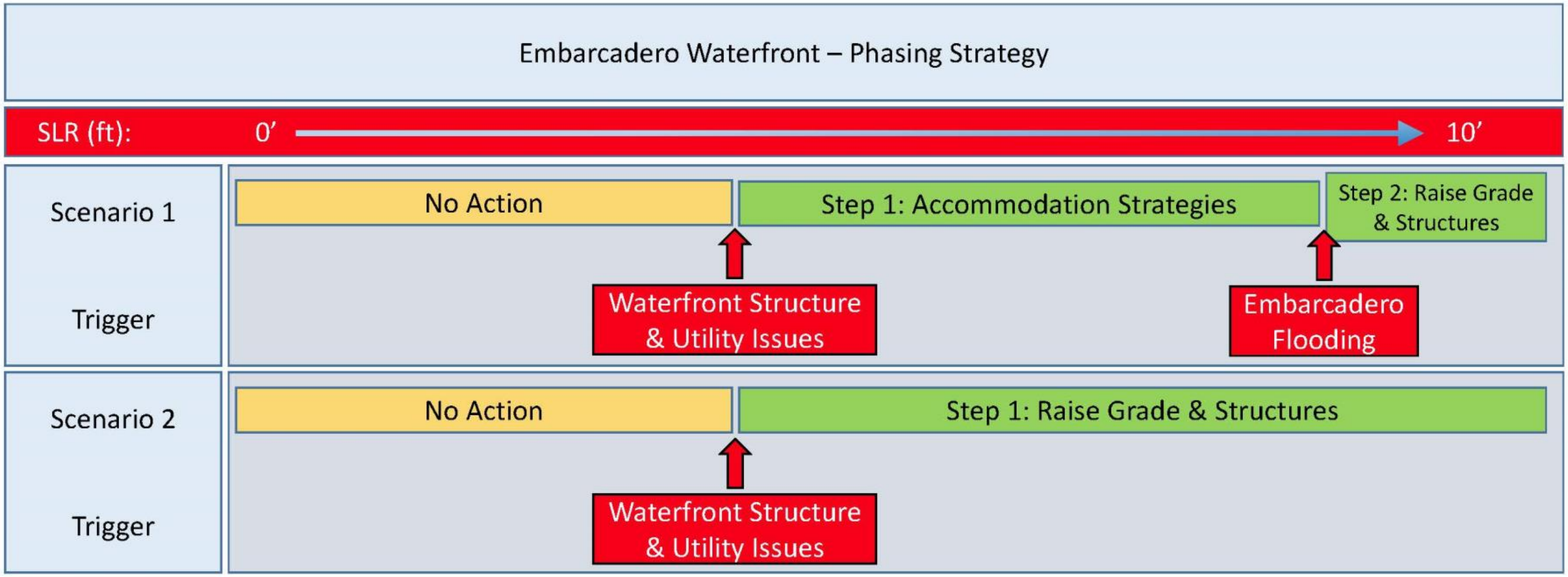


FIGURE 5-8. EMBARCADERO WATERFRONT – PHASING STRATEGY

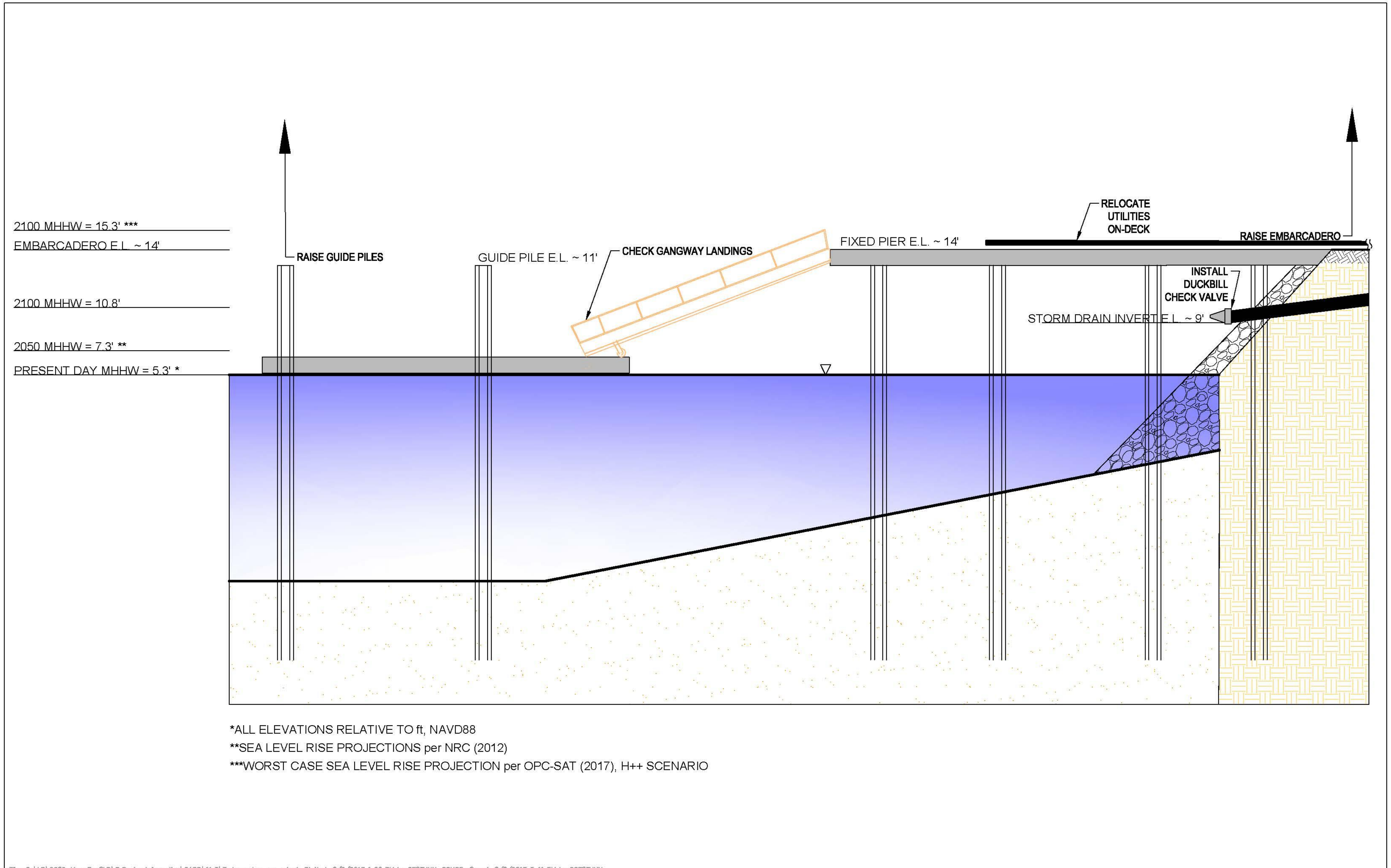


FIGURE 5-9. EMBARCADERO WATERFRONT – VULNERABLE ASSETS

6. Conclusions

The adaptation strategies presented in this report are conceptual and were developed to inform policy development and long-term planning decisions in the Morro Bay coastal zone. The strategies do not represent an exhaustive list of available options for the three sites and various combinations of the strategies presented could form a new viable alternative or phasing strategy. The City would conduct a more formal vetting process with stakeholders and the public should there be a desire to carry forward any of the strategies presented in this report. Thus, this report does not make recommendation of preferred alternatives for each of the study sites analyzed.

However, it is recommended that the City take some actions now so that implementation of future adaptation strategies can be done efficiently and at the appropriate times. It is recommended that the City take the following steps toward this goal:

- Develop a long-term monitoring program – The City should begin or formalize existing efforts to monitor beaches and flooding events. Documenting beach and dune changes as well as the frequency and severity of flooding events is helpful for City decision making and for applying for permits or grants to implement a future project.

- Identify funding mechanisms – The City should determine where funding would come from for future adaptation projects. State and Federal grants, development projects or lease renewals may all present potential project funding opportunities for these projects.

- Zoning and land use consistencies - Make proposed zoning and land uses in the General Plan/Local Coastal Plan consistent with adaptation approaches being considered in these study areas and other vulnerable areas within the City.

- Define triggers for adaptive actions – Triggers for implementation of the various strategies presented depend on the City and the community's acceptance of risk of the coastal hazards presented in this report. For example, the risk of flooding in the Morro Rock parking is likely more acceptable than that same flooding risk at Highway 1. Further dialogue should take place between the City, stakeholders and the public to more explicitly define triggers (i.e. when adaptation actions will be taken) and what actions will then be prompted. These discussions should include consideration of potential secondary impacts and trade-offs of a given strategy, as discussed in this report.

7. References

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